Four Empirical Studies on Games of Investment and Cooperation

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Preface

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Introduction

This thesis is a collection of four empirical studies. Three of them investigate topics related to industrial organization and one analyzes cooperation in a social dilemma game. Two-stage investment games are investigated in the first three chapters. Each of these chapters addresses a different question, Chapter 1 focuses on the strategic investment incentive which is a driving source for choices made in two-stage games. Chapter 2 analyzes the relationship between competition and investment in R&D and Chapter 3 investigates the investment incentives induced by patent protection or subsidization of R&D investments.

The analysis of Chapter 1 shows that subjects react to strategic investment incentives, in particular their reaction depends on the strategic environment, i.e., whether the choice variables are strategic substitutes or complements. Further their reaction depends on the externality imposed by their choice in the second stage, i.e., the externality on the other subject's profit can be positive or negative. The theoretical framework used in the experimental study is a two-stage game in which two firms make a stochastic investment in the first stage and compete in a market stage afterward. The treatments are varied with respect to three dimensions, (i) the strategic relation of the second stage choices is switched between complements and substitutes, (ii) the choice in the second stage imposes either a positive or negative externality on the other firm's profit, and (iii) the extent of information provided to the subjects is varied.

The main result of this study is that there is no significant deviation from the predicted subgame perfect equilibrium investment in three of four strategic substitutes treatments. But in all strategic complements treatments overinvestment is significant with respect to the predicted equilibrium investment. This finding can be partly explained by subjects' behavior in the second stage, namely subjects are not taking the outcome of the other subject's first stage choice into account when making their second stage decision. Only in the setting of strategic complements and negative externalities they do account for it. This result is supported by the finding of no significant deviations from the predicted second stage choices in the negative externality treatments, but of significant deviations in the positive externality treatments. Further support is provided by the fact that there are no significant deviations from the predicted Nash equilibrium as well as from the predicted non-strategic equilibrium investment in the first stage for the negative externality and strategic substitutes treatments. Concerning the treatment variation with respect to information, it can be shown that there are significant differences and that they depend on the strategic relation, the externality setting, and the outcome of the first stage.

Chapter 2 focuses on the effects of more intense competition on firms' investments in process innovations. More intense competition corresponds to an increase in the number of firms or a switch from Cournot to Bertrand competition. The model implemented in the laboratory is a two-stage game, where R&D investment choices are followed by product market competition. The treatment variations are (i) the number of firms in the market, (i) the kind of competition, Bertrand or Cournot, in the market stage, and (iii) whether the game is implemented as a two-stage or as a one-stage game. The main findings are that an increase in the number of firms from two to four reduces investments, whereas a switch from Cournot to Bertrand increases investments, even though theory predicts a negative effect in the four-player case. The results arise both in treatments in which both stages are implemented and in treatments in which only one stage is implemented. However, the positive effect of moving from Cournot to Bertrand competition is more pronounced in the former case.

Two well known policy instruments, patent protection and subsidization of R&D expenditures, are under investigation in Chapter 3. In particular, the effects of the two instruments on R&D investment decisions are analyzed. The theoretical framework is, as in the previous two chapters, a two-stage game consisting of an investment and a market stage. In equilibrium, both patents and subsidies induce the same amount of R&D investment, which is higher than the investment without governmental incentives. In the first stage, the firms can invest in a stochastic R&D project which might lead to a reduction of the marginal production costs and in the second stage, the firms face price competition. Both stages of the game are implemented in a laboratory experiment and the obtained results support the theoretical predictions. Patents and subsidies increase investment in R&D and the observed amounts of investment in the patent and subsidy treatment do not differ significantly across both instruments. However, we observe overinvestment in all three treatments. Observed prices in the market stage converge to equilibrium price levels.

In the final chapter I turn to a rather different topic, namely to cooperative behavior in a social dilemma. In Chapter 4 data from the British television game show "Golden Balls" is used to analyze behavior in a prisoner's dilemma game with high stakes, face-to-face communication, and two rounds of pre-play. The stake size in this game show is on average £13,300 and ranges from £3 to £100,150. During the pre-play the two final contestants are endogenously selected via a voting process. The main results are a unilateral cooperation rate of 55% and a mutual cooperation rate of 33%. The analysis shows that both stake size and communication have a significant impact on the player's likelihood to cooperate. In particular, a negative correlation between stake size and cooperation is observed. Also certain gestures, such as handshakes, decrease the likelihood to cooperate. But, if players mutually promise each other to cooperate and in addition shake hands on it, the cooperation rate increases. Further, it is shown that a player's expectation about the stake size matters and that there is a strong link between contestant's pre-play behavior and the outcome of the prisoner's dilemma. Players who contribute more to the stake size are less likely to cooperate, even though each player's contribution is determined by a random process. Addressing the partner selection process, the contestant's voting decisions are based on objective criteria, i.e., their opponent's monetary contribution to the stake size, as well as on subjective personal characteristics. Players strategically select their partner for the prisoner's dilemma, e.g., they bear in mind whether contestants lied.

Chapter 1

Strategic Investment Incentives in Two-Stage Games: Substitutes versus Complements

1 Introduction

Utility maximizing economic agents have to take the reaction of other agents to their own actions into account when interacting with other agents. Thus, it is crucial for them to understand the effect of their own actions on the others' actions. For instance, in a market of two firms and homogeneous goods, a rise of the price by one firm usually induces the other firm to do the same. In this case the choice variables of the game are strategic complements since the impact on the other firm's marginal profit or on the other individual's utility is positive. The choices would be strategic substitutes, if an increase of the choice variable has a negative impact on the other firm's marginal profit or on the other individual's marginal utility. In other words the sign of the reaction function determines whether the choices are strategic substitutes or complements.

This paper investigates strategic investment incentives. These incentives arise in two-stage games in which a choice made in the first stage influences the decision in the second stage. A classic example for such a game is a two-stage investment game in industrial organization. There firms can invest in the first stage, for instance in a cost reducing technology, and compete in a market in the second stage. Thus, strategic investment incentives arise out of the impact of the own investment on the other firm's second stage choice. Strategic investment incentives exist in addition to the effect arising out of the impact of the own investment on the own choice in the second stage. The seminal papers by Fudenberg and Tirole (1984) and Bulow, Geanakoplos, and Klemperer (1985) are the first to categorize strategic investment incentives by the kind of investment and the strategic relation between second stage choices and their implication for market-entry decisions. The investment choice influences the firm's choice in the second stage where the choices are either strategic substitutes or complements. The effect driving the investment decision in the first stage is the strategic investment incentive.

In order to systematically investigate the strategic investment incentive, I develop a static two-stage investment game. The basic idea is simple: I set up a model that yields the same subgame perfect Nash equilibrium investment independent of the strategic setting in the second stage. The second stage follows the model used by Potters and Suetens (2009) and thus allows me also to control for the framing effect which might arise out of the kind of externality imposed by the second stage choice. In the first stage firms can make a stochastic investment which increases a parameter in the profit function and thereby influences the own and the other firm's equilibrium choice in the second stage. I use a stochastic investment in the first stage in order to avoid a whole range of otherwise possible outcomes in the second stage as it would be the case with a continuous deterministic investment. In addition to the variation of the sign of the externality and the strategic relationship in the second stage, I implement a third treatment variation with respect to the amount of information a subject receives after the first stage. A subject is informed either about the outcome of its own and the other subject's investment or also about the investment choice of the other subject. This variation has no influence on the choices made by the firms in the first and in the second stage but allows me to control for whether subjects are using their first stage choice to, for instance, signal something about their second stage choice.[1]

Compared to the existing literature this paper is to the best of my knowledge the first to systematically test how the strategic investment incentive performs in the laboratory. Of course, there are other experimental studies which involve strategic investment incentives and in which the treatments differ with respect to the strategic relation of the choice variables, but the treatments differ in other dimensions as well (e.g., Sacco and Schmutzler (2011) and Chapter 2). The results of these studies provide first insights that there might be a connection between the observed deviations from the theoretically predicted investment choice and whether the choices at the second stage are strategic complements or substitutes. For instance, in Chapter 2 we find significant overinvestment with respect to predicted equilibrium investment in

[1] Huck, Normann, and Oechssler (2000) have shown that providing additional information about individual choices of firms in Cournot and Bertrand markets increases the competition in these markets in the laboratory.

all Bertrand treatments, but not in the Cournot treatments. A clear-cut comparison of the strategic investment incentives with regard to the strategic environment is, however, not possible in these studies because other treatment variations are made at the same time.

Investment games are not the only two-stage games in which strategic incentives play a decisive role. Instead of investing in cost reduction, the first stage decision could be how much to spend for advertising, which product standard is used, or which location should be chosen for production. There are experimental studies investigating strategic incentives in such different contexts. Engelmann and Normann (2007) study a strategic trade policy model where in the first stage the government can choose to subsidize domestic firms which then compete in Cournot market in the second stage. The results show that the first-period actions are not as high as predicted by theory. Oechssler and Schuhmacher (2004) analyze whether firms with limited liability use debt to commit to aggressive behavior in Cournot markets as predicted by the model of Brander and Lewis (1986). They find that subjects do so, but to a lower degree than predicted by the model. While addressing strategic delegation from firm owners to mangers in a Cournot duopoly, Huck, Müller, and Normann (2004) show that the predicted contract of output-based payment is only rarely chosen. In contrast to this paper, none of the three studies does systematically vary the strategic incentives influencing the decision made in the first stage.

The impact of the strategic environment on choices made in one-stage games is analyzed among others by Fehr and Tyran (2005) and Camerer and Fehr (2006). They provide experimental evidence that the strategic relation is an important determinant of aggregate outcomes. In particular, they show that a small amount of individual irrationality is more likely to lead to deviations from predicted rational outcomes under strategic complements than under strategic substitutes. Further, a small group of rational agents suffices to reach predicted outcomes under strategic substitutability. This follows the idea of the models of Haltiwanger and Waldman (1989) and Haltiwanger and Waldman (1985) who show that the impact of a given number of irrational agents on the aggregate outcome is different under strategic substitutes and complements. It is larger under strategic complements since rational agents have an incentive to follow the deviation of an irrational player in such an environment.

Experiments on non-differentiated[2] Bertrand and Cournot markets have shown that collusive outcomes are more often observed in Bertrand than in Cournot markets, see Suetens and Potters (2007) for an overview of the results of four experimental studies. As price choices in homogeneous Bertrand markets are strategic complements and quantity choices in homogeneous Cournot markets are strategic substitutes it

[2]In differentiated markets the evidence is not so clear: Davis (2010) finds that Bertrand markets with goods being close substitutes converge faster to Nash predictions than Cournot markets.

suggests itself that there might be a connection between the observed deviations from equilibrium in Bertrand games and the property of strategic complements. Potters and Suetens (2009) systematically analyze the effect of switching the strategic relation between the choice variables on the likelihood of collusive outcomes. In addition they vary the treatments with respect to the externality imposed by the choice variable on the other firm's profit, i.e., the externality can be positive or negative. They implement this additional feature to control for framing effects which are known as a source of influence on experimental outcomes (see e.g., Hoffman, McCabe, Shachat, and Smith (1994)).

The main result of this paper is that the strategic investment incentive plays a role in the decision making in the first stage, but not in all treatments. In three of four strategic substitutes treatments I find no significant deviation from the predicted subgame perfect equilibrium investment. In all strategic complements treatments I find significant overinvestment with respect to the predicted equilibrium investment. This observation can be partly explained by subjects' behavior in the second stage, namely subjects are not taking the other subject's first stage choice into account when making their second stage decision. This result depends on the strategic environment and the externality framing. Only in the setting of strategic complements and negative externalities they do account for the other subject's first stage choice. This result is supported by the finding of no significant deviations from the predicted second stage choices in the negative externality treatments, but of significant deviations in the positive externality treatments. Further support is provided by the fact that I cannot report significant deviations from the predicted Nash equilibrium as well as from the predicted non-strategic equilibrium investment in the first stage for the negative externality and strategic substitutes treatments. Concerning the treatment variation with respect to information, I show that there are significant differences and that they depend on the strategic relation, the externality setting, and the outcome of the first stage. In the information treatments the second stage choice is significantly positively correlated with the first stage choice, even if the investment has not been successful in the first stage. The correlation is not significant if no information about the other subjects' investment choice is provided.

The paper is organized as follows. In Section 2 I introduce the theoretical framework, the parameterization of the model and derive the main hypotheses. The design of the experiment is described in Section 3, followed by a presentation of the analysis and the results in Section 4. Section 5 concludes.

2 Theoretical Framework and Hypotheses

Before I present the model, I will briefly define the object of investigation of this paper, the strategic investment incentive.

Consider a simple static two-stage game in which two firms compete in a market after both firms had the possibility to invest in a profit-enhancing technology in the first stage. Each firm i with $i \in \{1, 2\}$ can reduce its marginal costs by investing r_i.[3] The cost reduction induces a change in the firm's strategy a_i in the market stage. The investment incentive of firm i can be expressed as the derivative of firm i's profit $\Pi_i(a_i, a_j, r_i)$ with respect to the investment r_i:

$$\frac{d\Pi_i(a_i, a_j, r_i)}{dr_i} = \underbrace{\frac{\partial \Pi_i}{\partial r_i}}_{\text{I}} + \underbrace{\frac{\partial \Pi_i}{\partial a_i}\frac{da_i}{dr_i}}_{\text{II}} + \underbrace{\frac{\partial \Pi_i}{\partial a_j}\frac{da_j}{dr_i}}_{\text{strategic effect}} \tag{1}$$

with $j \neq i$. Thus, the investment incentive of firm i consists of three parts, a direct and two indirect investment incentives. The first term (I) in equation (1) describes the direct effect of an investment r_i on firm i's profit, whereas the second and third term present indirect effects of investment. The investment changes firm i's choice a_i and firm j's choice a_j, but the effect on a_i (II) equals zero in equilibrium since firm i chooses a_i according to the first order condition. The effect of the investment on a_j is the strategic effect of investment. Fudenberg and Tirole (1984) show under which circumstances firms "overinvest" ("underinvest") in equilibrium compared to the mere direct investment incentive. They strategically overinvest (underinvest) if the strategic effect is positive (negative). The sign of the strategic effect is determined by the strategic relation of a_i and a_j and by the externality imposed by a_i on Π_j:

$$sign\left(\frac{\partial \Pi_i}{\partial a_j}\frac{da_j}{dr_i}\right) = sign\left(\frac{\partial \Pi_j}{\partial a_i}\frac{da_i}{dr_i}\right) sign\left(\frac{da_j}{da_i}\right) \tag{2}$$

For this decomposition to hold, it has to be assumed that the externality of firm i's choice a_i on firm j's profit Π_j is of the same sign as the externality of firm j's choice a_j on firm i's profit Π_i ($sign(\frac{\partial \Pi_i}{\partial a_j}) = sign(\frac{\partial \Pi_j}{\partial a_i})$). The effect of firm i's investment r_i on firm j's choice a_j can be rewritten as $\frac{da_j}{dr_i} = \frac{da_j}{da_i}\frac{da_i}{dr_i}$. Hence, the sign of the strategic effect depends on the the strategic relation between a_i and a_j ($\frac{da_j}{da_i}$) and the "kind" of investment ($\frac{d\Pi_j}{dr_i}$). In terms of Fudenberg and Tirole (1984) an investment can be of two different kinds: It is either "tough" or makes firm i "tough" if $\frac{d\Pi_j}{dr_i} < 0$, or it is "soft" if $\frac{d\Pi_j}{dr_i} > 0$. Which of the two is the case is determined by the effect

[3] For this introductory example, I use a deterministic investment. Of course, the investment incentives could also be defined in expectations, if the investment is stochastic and reduces the marginal costs only with a certain probability.

of the investment r_i on a_i and the externality imposed by a_i on π_j, e.g., if $\frac{d\Pi_j}{da_i} > 0$ and $\frac{da_i}{dr_i} > 0$ the investment is soft.

In the following I present the model which will then be used to derive the hypotheses tested in the experiment. The model allows for strategic substitutes or complements as well as for positive or negative externalities of the second stage choice while keeping the investment in the first stage fixed to be of soft kind.

2.1 The Model

In my two-stage model, an investment stage precedes a product market competition stage. As backward induction is used to solve for the subgame perfect equilibrium investment, I present the market stage first and the investment stage afterward.

The model used in the market stage follows the framework of Potters and Suetens (2009). In particular, I use their reduced-form payoff function because it allows me to independently vary the sign of the externality imposed by the choice variable on the other firms's profit and the sign of the reaction function. This is very convenient with respect to an implementation in the laboratory.

2.1.1 Market Stage

The profit function π_i of firm $i \in \{1, 2\}$, is given in reduced form as follows:

$$\pi_i(x_i, x_j, b_i) = a + b_i x_i + c x_j - d x_i^2 + e x_j^2 + f x_i x_j \tag{3}$$

with $i \neq j$, $j \in \{1, 2\}$ and a, b_i, c, $d > 0$, e, x_i, $x_j \geq 0$, and $f \neq 0$. The underlying demand system and production technology is not further specified, but depending on the choice of parameters the profit function can be generated for instance by a linear demand and cost function in which case it is equal to a profit function of a standard Cournot duopoly (see Potters and Suetens (2009)). The sign of the f-parameter defines the strategic relationship between x_i and x_j. If f is positive, x_i and x_j are strategic complements $(\frac{\partial^2 \pi(x_i,x_j)}{\partial x_i \partial x_j} > 0)$ and if it is negative they are strategic substitutes $(\frac{\partial^2 \pi(x_i,x_j)}{\partial x_i \partial x_j} < 0)$. Further, x_i imposes a positive externality on firm j, i.e., firm j's profit is increasing in x_i, if $\frac{\partial \pi_j}{\partial x_i} > 0$ holds. Following Potters and Suetens (2009), the case of negative externalities is implemented by redefining the choice variable x_i to $(m - y_i)$. Thus an increase of y_i has to lead to a decrease of firm j's profit $(\frac{\partial \pi_j}{\partial y_i} < 0)$.[4] Hence, there is no difference in the equilibria of the positive and negative externality cases, but the constant m. I distinguish the two cases to

[4] In this case the profit function is given by: $\pi_i(y_i, y_j, b_i) = a + b_i(m - y_i) + c(m - y_j) - d(m - y_i)^2 + e(m - y_j)^2 + f(m - y_i)(m - y_j)$. The parameters have to be chosen such that $\frac{\partial \pi_j}{\partial x_i} = c + 2ex_i + fx_j$ is always positive and $\frac{\partial \pi_j}{\partial y_i} = -c - 2e(m - y_i) - f(m - y_j)$ is always negative.

control for framing effects which are possibly arising by the difference in choosing x_i or y_i.

There exists a unique and symmetric Nash equilibrium in each of the four cases. In the positive externality case the equilibirium is given by

$$x_i^*(b_i, b_j) = \frac{2db_i + fb_j}{4d^2 - f^2}, \tag{4}$$

and in the negative externality case by

$$y_i^*(b_i, b_j) = m - \frac{2db_i + fb_j}{4d^2 - f^2}. \tag{5}$$

If $f > 0$, x_i and x_j or y_i and y_j are strategic complements and if $f < 0$, they are strategic substitutes. As will be shown in the next section, the investment influences the b-parameter and thus it influences the equilibrium choice of the second stage.

2.1.2 Investment Stage

Each firm can invest k_i with $k_i \in [0, K)$. The investment is stochastic with a success probability of sk_i with $s > 0$. In case of success $b_i = b_h > 0$ and otherwise $b_i = b_l < b_h$ with $b_l > 0$. Thus the higher the investment, the higher is the probability of $b_i = b_h$. The cost of investment is assumed to be quadratic ($C(k_i) = tk_i^2$ with $t \geq 0$) in the investment. Four different outcomes can arise in the market, because each firm's b-parameter can either take on the value of b_l or b_h. Hence, the second-stage equilibrium profits are either $\pi_i(x_i^*(b_l, b_l), x_j^*(b_l, b_l))$, $\pi_i(x_i^*(b_h, b_h), x_j^*(b_h, b_h))$, $\pi_i(x_i^*(b_h, b_l), x_j^*(b_l, b_h))$, or $\pi_i(x_i^*(b_l, b_h), x_j^*(b_h, b_l))$. The expected profit $E[\Pi_i(k_i, k_j)]$ is then given by the sum of the equilibrium profits net of investment costs and weighted with the probability of occurrence:

$$E[\Pi_i(k_i, k_j)] = sk_i \left(sk_j\pi_i^{hh} + (1 - sk_j)\pi_i^{hl}\right) + (1 - sk_i)\left(sk_j\pi_i^{lh} + (1 - sk_j)\pi_i^{ll}\right) - tk_i^2. \tag{6}$$

Maximizing the expected profit $E[\Pi_i(k_i, k_j)]$ with respect to k_i yields the symmetric subgame perfect equilibrium investment k_i^* as follows:

$$\begin{aligned} k_i^* &= \frac{s(\pi_i^{hl} - \pi_i^{ll})}{s^2(\pi_i^{hl} - \pi_i^{ll} + \pi_i^{lh} - \pi_i^{hh}) + 2t} \\ &= \frac{(b_h - b_l)\left(4(b_h + b_l)d^3 + 4d(cd + b_l(d + e))f + (b_h + b_l)ef^2 - cf^3\right)s}{2\left(-4d^2 + f^2\right)^2 t - 4(b_h - b_l)^2 d(d + e)fs^2} \end{aligned} \tag{7}$$

The subgame perfect equilibrium investment k_i^* is the same for both positive and negative externalities and depends among others on the parameter f. The sign of f determines whether x_i and x_j or y_i and y_j are strategic substitutes or complements and thus changes k_i^* ceteris paribus. Thus, the equilibrium investment is determined by the profit differences of the four outcomes. The investment choices k_i and k_j are strategic complements ($\frac{dk_i}{dk_j} > 0$) if the second stage choices are strategic complements and they are strategic substitutes ($\frac{dk_i}{dk_j} < 0$) if the second stage choices are strategic substitutes.[5]

Table 1: Strategic incentive effects for the soft investment k_i

Externality	**Strategic Complements** ($\frac{dy_j}{dy_i} > 0$, $f > 0$)	**Strategic Substitutes** ($\frac{dy_j}{dy_i} < 0$, $f < 0$)
Positive ($\frac{d\pi_j}{dx_i} > 0$)	$k_i \rightarrow^1 b_i \uparrow \rightarrow x_i \uparrow$ overinvestment	$k_i \rightarrow b_i \uparrow \rightarrow x_i \uparrow$ underinvestment
Negative ($\frac{d\pi_j}{dy_i} < 0$)	$k_i \rightarrow b_i \uparrow \rightarrow y_i \downarrow$ overinvestment	$k_i \rightarrow b_i \uparrow \rightarrow y_i \downarrow$ underinvestment

[1] Note that the relation between k_i and b_i is stochastic.

Since $E[x_i]$ increases and $E[y_i]$ decreases with an increase of k_i, the investment is soft ($\frac{\partial \pi_j}{\partial k_i} > 0$) for both positive and negative externalities and for both strategic substitutes and complements. It is important to keep that property in mind because in most two-stage investment games analyzed in the literature, the kind of investment is tough and not soft. The sign of the strategic effect and thereby the prediction of over- or underinvestment compared to the investment incentive from the direct effect, however, depends on the strategic relation between x_i (y_i) and x_j (y_j). In case of strategic substitutes the strategic investment incentive is negative and the prediction is underinvestment and in case of strategic complements it is the other way around and the prediction is overinvestment. Fudenberg and Tirole (1984) refer to the strategy of a firm as being "lean and hungry" if the choices are strategic substitutes and the investment makes the firms soft. The soft investment weakens the position of the firm in the market and thus the firm will underinvest. If the choices are strategic complements the strategy is called "fat cat" because the soft investment implies a friendly reaction by the competitor and thus induces the firm to overinvest in the first place. The sign of the strategic investment incentive is independent of the sign of the externality, see Table 1 for an overview.

In addition to the subgame perfect Nash equilibrium investment level, I compute the investment level that firms would choose in absence of the strategic investment incentive discussed in equation (2). This level will be used as the benchmark which I will refer as the direct investment incentive. Compared to the equilibrium prediction derived in equation (7) this prediction will result in underinvestment in case of strategic substitutes and in overinvestment in case of strategic complements. In

[5] In case of a tough investment, e.g., an investment that increases d, the strategic relation of the first stage choices could be contrary to the strategic relation of the second stage choices depending on the choice of parameters.

order to eliminate the strategic investment incentive of the objective function of firm i, I fix firm j's second-stage choice variable at the expectation $E[x_j(b_j(k_j), b_i(k_i))]$ arising if firms invest $k_i = k_j = k^*$ and firm j's first-stage investment at $k_j = k^*$.

$$\begin{aligned} E[\Pi_i(k_i)] &= a + E[b_i(k_i)x_i(b_i(k_i), b_j(k^*)) + cx_j(b_j(k^*), b_i(k^*)) \\ &- dx_i(b_i(k_i), b_j(k^*))^2 + ex_j(b_j(k^*), b_i(k^*))^2 \\ &+ fx_i(b_i(k_i), b_j(k^*))x_j(b_j(k^*), b_i(k^*))] - C(k_i) \end{aligned} \tag{8}$$

Maximizing the expected profit with respect to k_i, yields the equilibrium investment of firm i, $k_i^* \Big|_{k_j = k_j^*, E[x_j(b_j(k^*), b_i(k^*))]} \equiv k_i^* \Big|_{k_j^*, E[x_j^*]}$, which is conditional on the profit maximizing behavior of firm j in the first stage and on the expected profit maximizing behavior in the second stage:

$$k_i^* \Big|_{k_j^*, E[x_j^*]} = \frac{(b_h - b_l)(8b_l d^3 - 8x_j d^3 f - 4b_l df^2 + (b_j + 2x_j d)f^3)s}{2(-4d^2 + f^2)^2 t - 4(b_h - b_l)^2 d(2d^2 - f^2)s^2} \text{ and} \tag{9}$$

$$k_i^* \Big|_{k_j^*, E[x_j^*]} = \frac{(b_h - b_l)s(b_l(8d^3 - 4df^2) - f(b_j f^2 - 2d(2d - f)(2d + f)(m - y_j)))}{2(-4d^2 + f^2)^2 t - 4(b_h - b_l)^2 d(2d^2 - f^2)s^2} \tag{10}$$

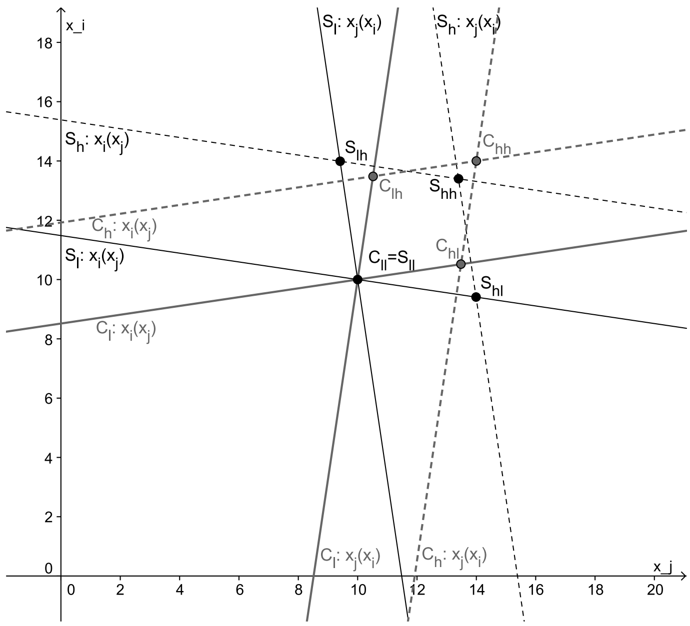
for the negative externality case.

2.2 Parameterization and Hypotheses

In order to be able to test whether there are differences in the performance and perception of the investment incentive between the four settings, I will set the parameters such that the subgame perfect equilibrium investment k_i^* is the same in all four settings. In the following I will refer to the four situations as SP, SN, CP, and CN which stand for "strategic substitutes with positive externalities", "strategic substitutes with negative externalities", "strategic complements with positive externalities", and "strategic complements with negative externalities".
In the second stage the slopes of the reaction functions are equal in absolute value. In addition, in the second stage of the SP and CP condition, the equilibrium choices $x_i(b_l, b_l) = x_i(\beta_l, \beta_l) := x_{ll}$, and thus the equilibrium profits $\pi_i^*(x_{ll}, x_{ll})$ are equal if both firms are not successful in the first stage (see Figure 1 at $C_{ll} = S_{ll}$). The same holds for the negative externality condition. It however is impossible to equalize the equilibrium choices for all four outcomes of the first stage at the same time without letting go the property of strategic complements and substitutes. Figure 1 illustrates the reaction functions and equilibiria in the second stage for the SP (thin black lines) and the CP (thick gray lines) condition.

To equalize equilibrium investments I use the same parameters for a, c, d, e, m, s, and t in all four settings. The f parameter is the same in absolute value for strategic substitutes and complements, but differs in its sign. The parameters are set as follows: $a = -30$, $c = 2.515$, $d = 0.278$, $e = 0.0055$, $f = 0.0825$, $\zeta = -0.0825$, $m = 30$,

Figure 1: Best-response functions for CP and SP



$s = 0.2$, and $t = 1.2$.[6] For the chosen parameterization x_i (y_i) imposes always a positive (negative) externality on π_j, independent of $x_j \in (0, 30)$ ($y_j \in (0, 30)$). The parameters b_l and b_h are used to compensate the difference arising from the opposite signs of the f parameter and the thereby caused differences in profits (see Footnote 6). Therefore the two parameters are different for the strategic complements and substitutes setting. In CP and CN they are set to be $b_l = 4.735$ and $b_h = 6.629$ and in SP and SN they are chosen to equal $\beta_l \approx 6.385$ and $\beta_h \approx 8.555$. With the chosen parameterization of the model the theoretical predictions can be calculated, the results are presented in Table 2.

Finally, the hypotheses for the experiment can be derived from the theoretical predictions:

Hypothesis 2.1. *Independent of the sign of externality and independent of the strategic relation of the choice variables in the second stage, the subgame perfect equilibrium investment is* $k_i^* = 2.04$.

Hypothesis 2.2. *The subgame perfect equilibrium choice equals* x_i^* *under the condition of positive externalities and* y_i^* *under the condition of negative externalities, further* x_i^* *equals* $m - y_i^*$ *in the corresponding strategic setting.* x_i^* *and* y_i^* *depend on the outcome of the first stage.*

[6] In the following Greek letters will be used to denote parameters in the strategic substitutes setting that are different from the parameters in the strategic complements setting. Note, that the chosen parameterization follows Potters and Suetens (2009) in some parts.

Table 2: Theoretical predictions for CP, CN, SP, and SN

Strategic Complements			
Positive Externality			**Negative Externality**
Slope $x_i(x_j)$	0.1484	0.1484	Slope $y_i(y_j)$
$x_i^*(b_l, b_l)$	10	20	$y_i^*(b_l, b_l)$
$x_i^*(b_h, b_h)$	14	16	$y_i^*(b_h, b_h)$
$x_i^*(b_l, b_h)$	10.5168	19.4832	$y_i^*(b_l, b_h)$
$x_i^*(b_h, b_l)$	13.4832	16.5168	$y_i^*(b_h, b_l)$
$\pi_i^*(x_{ll}, x_{ll})$	23.5	23.5	$\pi_i^*(y_{ll}, y_{ll})$
$\pi_i^*(x_{hh}, x_{ll})$	60.776	60.776	$\pi_i^*(y_{hh}, y_{hh})$
$\pi_i^*(x_{lh}, x_{hl})$	35.6579	35.6579	$\pi_i^*(y_{lh}, y_{hl})$
$\pi_i^*(x_{hl}, x_{lh})$	47.5474	47.5974	$\pi_i^*(y_{hl}, y_{lh})$
k_i^*	2.0429	2.0429	k_i^*
$E[x_i^*]$	11.6343	18.3657	$E[y_i^*]$
$E[\pi_i^*]$	33.4754	33.4754	$E[\pi_i^*]$
$k_i^* \Big\vert_{k_j^*, E[x_j^*]}$	1.8114	1.8114	$k_i^* \Big\vert_{k_j^*, E[x_j^*]}$
Strategic Substitutes			
Positive Externality			**Negative Externality**
Slope $x_i(x_j)$	-0.1484	-0.1484	Slope $y_i(y_j)$
$x_i^*(\beta_l, \beta_l)$	10	20	$y_i^*(\beta_l, \beta_l)$
$x_i^*(\beta_h, \beta_h)$	13.3984	16.6016	$y_i^*(\beta_h, \beta_h)$
$x_i^*(\beta_l, \beta_h)$	9.4079	20.5921	$y_i^*(\beta_l, \beta_h)$
$x_i^*(\beta_h, \beta_l)$	13.9905	16.0095	$y_i^*(\beta_h, \beta_l)$
$\pi_i^*(x_{ll}, x_{ll})$	23.5	23.5	$\pi_i^*(y_{ll}, y_{ll})$
$\pi_i^*(x_{hh}, x_{ll})$	54.59	54.59	$\pi_i^*(y_{hh}, y_{hh})$
$\pi_i^*(x_{lh}, x_{hl})$	30.868	30.868	$\pi_i^*(y_{lh}, y_{hl})$
$\pi_i^*(x_{hl}, x_{lh})$	48.5618	48.5618	$\pi_i^*(y_{hl}, y_{lh})$
k_i^*	2.0429	2.0429	k_i^*
$E[x_i^*]$	11.3885	18.6115	$E[y_i^*]$
$E[\pi_i^*]$	31.5183	31.5183	$E[\pi_i^*]$
$k_i^* \Big\vert_{k_j^*, E[x_j^*]}$	2.062	2.062	$k_i^* \Big\vert_{k_j^*, E[x_j^*]}$

With an equilibrium investment of $k_i^* = 2.04$, the probability of a single firm being successful is 48.33 %, of both firms being successful is 16.69 % and of none of the firms being successful is 34.98 %.

3 Experimental Design

With the theoretical framework described in the previous section, I can test the following four conditions of the two-stage investment game (see Table 3). Apart from the four treatments that arise naturally due to the setup of the model, namely the SP, SN, CP, and CN treatment, I run four additional treatments which differ with respect to the information given to the subjects. These treatments are called SPi, SNi, CPi, and CNi.

For all treatments both stages are implemented in the laboratory. Subjects are informed about the outcome of the first stage and the second stage. After the first

Table 3: Overview of the treatments

	Strat. Complements ($\frac{dx_j}{dx_i} > 0$)	**Strat. Substitutes** ($\frac{dx_j}{dx_i} < 0$)
Pos. Externality ($\frac{d\pi_j}{dx_i} > 0$)	soft investment, overinvestment (SP, SPi)	soft investment, underinvestment (CP, CPi)
Neg. Externality ($\frac{d\pi_j}{dx_i} < 0$)	soft investment, overinvestment (SN, SNi)	soft investment, underinvestment (CN, CNi)

stage they get to know whether they and their opponent have been successful or not, i.e., whether they and their opponent have b_l (β_l) or b_h (β_h). In the information treatments they are not only informed about the outcome of the first stage, but also about the investment level chosen by their opponent. In the following I will refer to these treatments as "information" and "no-k-information" treatments. After the second stage subjects are informed about their own and their opponent's choice as well as their own profit. The instructions are not framed, i.e., the subjects are not referred to as firms and the second stage choice is not attached a label such as price or quantity. Further the investment is explained to determine the type of the subject, i.e., a subject having the low b (β)-value is of type A and a subject having the high value is of type B.[7]

Whether subjects are merely informed about the outcome of the first stage or as well informed about the investment choice should have no influence on the second stage choice. However, one could imagine that subjects use the first stage choice as a signaling device for the second stage choice, i.e., a low (high) first stage choice could signal a low (high) second stage choice. Thus, I state a third hypothesis:

Hypothesis 3.1. *The investment k^* and the second stage choice x^* or y^* are the same in the corresponding treatments independent of the information condition.*

The experiment was run in the experimental laboratory of the University of Zurich in November 2010.[8] Altogether 184 subjects were recruited and the number of subjects per treatment varied between 12 and 32. The subjects were mostly students from the University of Zurich and the Swiss Federal Institute of Technology Zurich. The subjects' average earnings were lowest in the SNi treatment with CHF 31.55 and highest in the CPi treatment with CHF 33.01 (see Table 9 in Appendix A.2 for detailed information).

Each treatment was conducted in a separate session and stranger matching was used within groups of four subjects. Thus, subjects were matched to new pairs after

[7]See Appendix A.3 for the instructions.

[8]The subjects were recruited using ORSEE (Greiner (2004)) and the experiment was programmed with z-Tree (Fischbacher (2007)).

each period within a matching group, but not between matching groups. Therefore, each matching group represents an independent observation. The two-stage game was played for 15 periods, however in some sessions only fewer periods could be played due to the time constraint of 90 minutes per session. The subjects were given the instructions on paper and after reading them they had to answer control questions in order to make sure that they understood the instructions. The subjects were given payoff tables that displayed their earnings in the second stage for integer x or y choices and tables displaying the investment costs and the success probabilities for some choices of k. In addition they could use calculators provided on the computer screen during the experiment to calculate their investment costs and success probabilities in the first stage as well as their profits and their opponent's profit in the second stage. There the calculation cloud be done at a precision of 0.01 points of the choice variables. Therefore, it is reasonable to use the continuous predictions of the model as theoretical benchmarks.

4 Analysis and Results

First I present the results concerning the investment stage and secondly the ones concerning the market stage.

4.1 Investment Stage

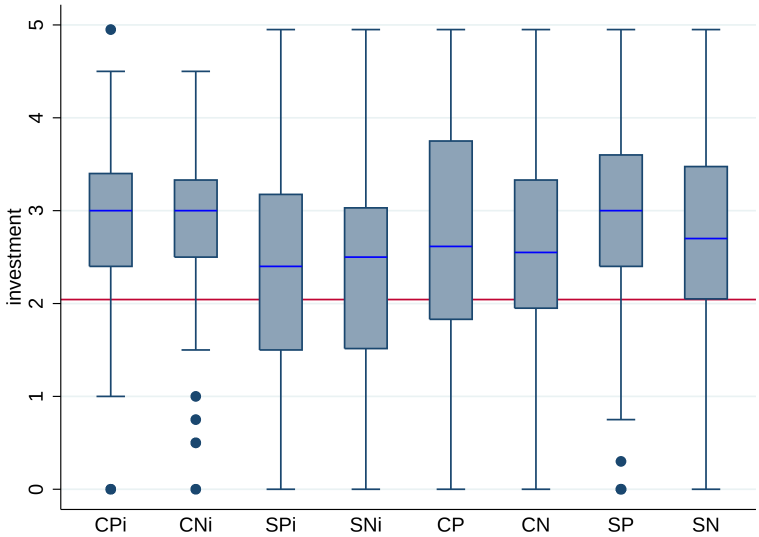
Figure 2 provides a first overview of the observed investment choices in the eight conducted treatments. The boxplots show that the within-treatment dispersion of the observed investment data is rather large and only noticeably smaller in the CPi and CNi treatments. In those two treatments the median value of investment is also higher than in the other treatments. Among the no-k-information treatments only the SP treatment has an equally high median value and a smaller dispersion of the data. The distribution of chosen investment levels for all treatments is depicted in Figure 7 in Appendix A.1.

In order to test for significant differences between the treatments, non-parametric tests are used.[9] A first analysis of the investment decisions shows that the aggregated observations could have all been drawn from the same distribution.[10] However, there are significant differences between treatments. Separating the observations on the basis of the information condition shows that the observed average investment levels of the four information treatments (CPi, CNi, SPi, and SNi) cannot have

[9] All non-parametric tests in this paper are computed on the basis of matching group averages.

[10] Using a Kruskal-Wallis test reveals that the null hypothesis of no differences between the matching group averages cannot be rejected (p=0.121).

Figure 2: Boxplots of observed investments



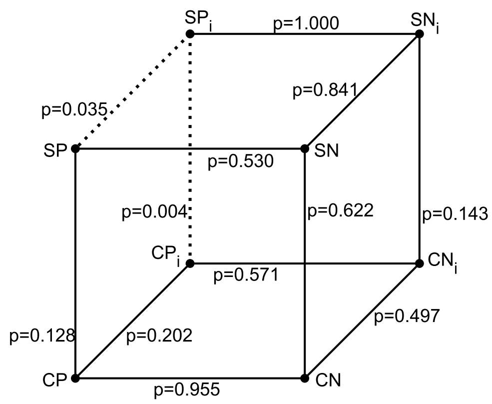
been drawn from the same distribution (p=0.040). The treatments from the no-k-information condition (CP, CN, SP, and SN) are not significantly different from each other (p=0.359). There are two additional dimensions that can be used to separate the observations, one is the strategic relation between the second stage choices and one is the externality imposed by this choice. Using the strategic relation reveals that there is neither a significant difference between the four complements treatments (p=0.166) nor between the four substitutes treatments (p=0.148). Separating the data by the sign of the externality shows that the null hypothesis of no difference between the four treatments can be rejected for the positive externality treatments (p=0.034), but not for the negative externality treatments (p=0.621).

Figure 3 illustrates the results of two-sided Mann-Whitney-U tests between the eight treatments. As one can immediately see, the null hypothesis of no difference between the treatments can only be rejected for SP vs. SPi (p=0.035) and for SPi vs. CPi (p=0.004). Thus, there is no significant difference between treatments if the negative vs. the according positive externality treatment is tested. These first results suggest that the observed investment level is influenced by the treatment variations with respect to the strategic relation and the information provision. The differences within the information and the positive externality treatments might be driven by the significant bilateral differences.

4.1.1 Deviations from k_i^*

Apart from the differences of observed investments between treatments, Figure 2 reveals that the median investment levels lie above the predicted equilibrium invest-

Figure 3: Results of two-sided Mann-Whitney-U tests



ment level depicted as a solid line at 2.04. To test for significant differences between the observed and predicted investment levels, I use OLS regressions

$$\Delta k_{i,t} = k_{i,t} - k^*_{i,t} = \alpha + \epsilon_{i,t} \tag{11}$$

with $k^*_{i,t} = 2.0429$ standing for the predicted equilibrium investment. If the deviation from equilibrium is significant the estimated constant α will be significantly different from zero. Table 11 in Appendix A.2 shows that the deviations are significant for all complements treatments (CPi, CNi, CP, and CN), but only for one of the four substitutes treatments, the SP treatment. The average overinvestment compared to the predicted equilibrium investment is between 19.55% and 39.80% in the complements treatments.[11] Recall that the sign of the strategic investment incentive is positive in the complements treatments and negative in the substitutes treatments independent of the sign of the externality. Thus, subjects might be over- or underestimating the strategic effect. Using OLS regressions to test for significant deviations from the non-strategic investment incentives increases (decreases), as expected, the estimated constant in the complements (substitutes) treatments and increases the significance levels.[12] Hence, subjects seem to underestimate the strategic investment incentive in the complements treatments and are thus investing significantly more than predicted.

Result 4.1. *The observed investment level is above the predicted equilibrium investment in all complements and the SP treatment. The same holds with respect to the predicted non-strategic equilibrium investment.*

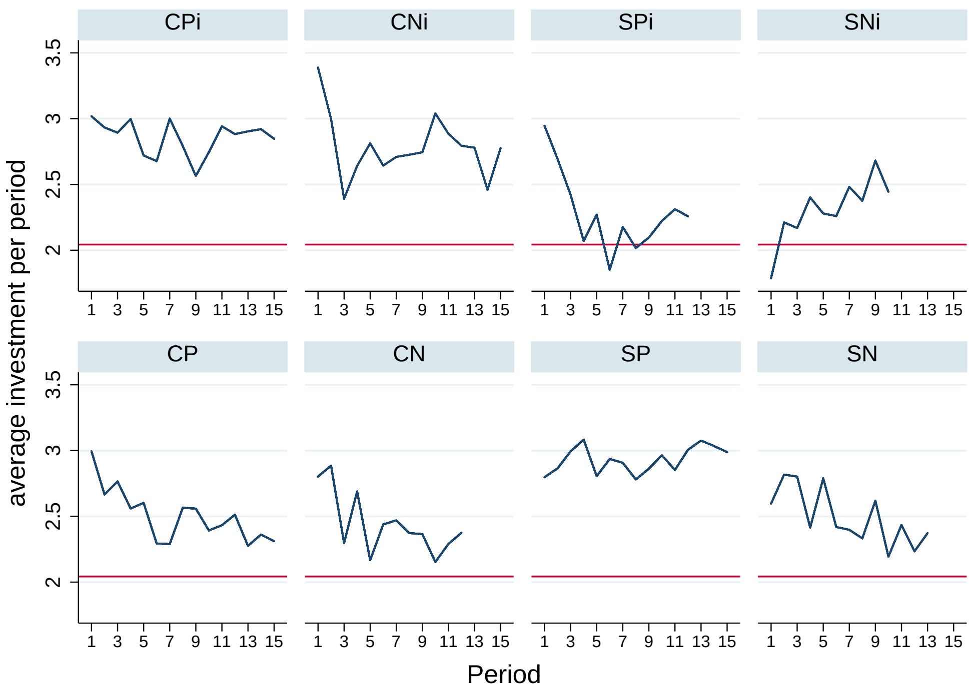
[11]See Table 10 in Appendix A.2 for average deviations from equilibrium for each treatment.

[12]See Table 12 in Appendix A.2 for the regression results of $\Delta k^{over/under}_{i,t} = \alpha + \epsilon_{i,t}$ with $k^*_{i,t} = 1.8114$ for the complementes, and $k^*_{i,t} = 2.062$ for the substitutes treatments, and with $\Delta k^{over/under}_{i,t} = k_{i,t} - k^*_{i,t}\Big|_{k^*_j, E[x^*_j]}$.

4.1.2 Influences of the Treatment Variations on Observed Investment

Further, it is interesting to see how the investment choices developed over time. Figure 4 shows the average investment levels for all treatments from the first to the last period.

Figure 4: Time series of observed investments by treatment



The predicted equilibrium investment level is depicted as a solid line at 2.04 in each graph. Except for the SPi and the SNi treatment, the average investment never drops below the equilibrium prediction, but remains above the prediction. The majority of the time series graphs reveals an initial decline in the investment choices. Whether this effect is significant can be tested by running regressions including dummy variables for being in the first half of the periods and by controlling at the same time for other treatment variations. I run separate regressions for each treatment condition, e.g., I separate the data on the basis of the information property and control for being in a strategic substitutes treatment or in a positive externality treatment. If I separate the data by the strategic relation or the externality condition, I include a dummy for being in an information treatment:

$$
\begin{aligned}
k_{i,t} &= \alpha + \beta_1 \text{ firsthalf}_{i,t} + \beta_2 \text{ substitutes}_{i,t} + \beta_3 \text{ posext}_{i,t} + \epsilon_{i,t} \\
k_{i,t} &= \alpha + \beta_1 \text{ firsthalf}_{i,t} + \beta_2 \text{ information}_{i,t} + \beta_3 \text{ posext}_{i,t} + \epsilon_{i,t} \qquad (12) \\
k_{i,t} &= \alpha + \beta_1 \text{ firsthalf}_{i,t} + \beta_2 \text{ information}_{i,t} + \beta_3 \text{ substitutes}_{i,t} + \epsilon_{i,t}
\end{aligned}
$$

Table 4: OLS regression results on investment

Treatments Separated by: Information				
$k_{i,t}$	Model (1)	Model (2)	Model (3)	Model (4)
firsthalf	0.025	0.144**	0.025	0.140**
	(0.065)	(0.062)	(0.065)	(0.061)
substitutes	-0.539***	0.269	-0.478*	0.057
	(0.134)	(0.223)	(0.256)	(0.416)
posext	0.018	0.231	0.070	0.068
	(0.149)	(0.224)	(0.189)	(0.201)
subst_posext			-0.101	0.367
			(0.295)	(0.474)
Constant	2.807***	2.285***	2.774***	2.372***
	(0.148)	(0.155)	(0.189)	(0.138)
R^2	0.064	0.022	0.064	0.026
N	968	1484	968	1484
No. of clusters	19	27	19	27
Data from:	CPi, CNi, SPi, SNi	CP, CN, SP, SN	CPi, CNi, SPi, SNi	CP, CN, SP, SN

Treatments Separated by: Strategic Relation				
$k_{i,t}$	Model (1)	Model (2)	Model (3)	Model (4)
firsthalf	0.049	0.137**	0.049	0.137**
	(0.063)	(0.065)	(0.063)	(0.064)
information	-0.468**	0.349**	-0.187	0.348
	(0.222)	(0.132)	(0.434)	(0.225)
posext	0.238	0.069	0.436	0.068
	(0.271)	(0.146)	(0.431)	(0.201)
inf_posext			-0.467	0.002
			(0.486)	(0.275)
Constant	2.594***	2.374***	2.472***	2.374***
	(0.308)	(0.126)	(0.397)	(0.138)
R^2	0.043	0.024	0.050	0.024
N	1168	1284	1168	1284
No. of clusters	23	23	23	23
Data from:	SPi, SP, SNi, SN	CPi, CP, CNi, CN	SPi, SP, SNi, SN	CPi, CP, CNi, CN

Treatments Separated by: Externality				
$k_{i,t}$	Model (1)	Model (2)	Model (3)	Model (4)
firsthalf	0.086	0.088	0.094	0.096
	(0.065)	(0.063)	(0.066)	(0.060)
information	-0.146	0.090	0.350**	0.347
	(0.172)	(0.250)	(0.159)	(0.225)
substitutes	0.011	-0.148	0.425*	0.056
	(0.178)	(0.284)	(0.228)	(0.419)
inf_subst			-1.006***	-0.536
			(0.270)	(0.490)
Constant	2.673***	2.481***	2.462***	2.394***
	(0.160)	(0.149)	(0.161)	(0.137)
R^2	0.005	0.006	0.045	0.016
N	1428	1024	1428	1024
No. of clusters	25	21	25	21
Data from:	CPi, CP, SPi, SP	CNi, CN, SNi, SN	CPi, CP, SPi, SP	CNi, CN, SNi, SN

Standard errors in parentheses are corrected for matching group clusters.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

In addition I include interaction variables of the two treatment dummies to test whether the conditions interact with each other. Then the regression equations include an additional term, either β_4 subst_posext$_{i,t}$, β_4 inf_posext$_{i,t}$, or β_4 inf_subst$_{i,t}$. The results of the regression analysis are presented in Table 4. Being in the first half of the periods has a significantly positive effect in the no-k-information treatments and in the complements treatments. Further, the impact of being in an information treatment on investment is twofold: It has a significantly negative effect in the substitutes treatments and a significantly positive effect in the complements treatments. Considering the positive externality treatments, being in the SPi treatment significantly decreases investment corroborating the results of the non-parametric tests. The strategic relation matters in the information, but not in the no-k-information treatments. Being in a strategic substitutes treatment decreases investment significantly in the information treatments, but it has a significantly positive effect on investment in the positive externality treatments if I control for an interaction effect with the information treatment. Being in a positive externality treatment has no significant effect in any of the models.

Result 4.2. *The observed investment level is significantly influenced by the information condition and the strategic relation of the second stage choice variables. The sign of the externality in the second stage seems to have no influence on the choice in the first stage. Further investment levels decrease in the second half of the periods in some of the treatments.*

4.1.3 Distribution of Outcomes of the First Stage

I will briefly analyze the distribution of outcomes of the investment stage. If the equilibrium investment k^* is chosen the number of successful firms are distributed as follows: In 48.33% of the cases one of the firms is successful and the other is not, in 16.69% both firms are successful, and in 34.98% neither firm is successful. Table 5 shows the observed distributions of outcomes of the first stage for the eight treatments. One can see that the share of only one firm being successful is rather similar for all treatments and also similar compared to the equilibrium prediction; it varies between 45% and 54% percent. In contrast the shares of the other outcomes show large variations between treatments: The fraction of outcomes in which none of the firms is successful varies between 11% and 29% and the fraction of outcomes in which both firms are successful varies between 17% and 43%. Using χ^2-tests to test for significant differences between the observed and predicted distribution reveals that all observed distributions are significantly different, but the one of the SPi and SNi treatment.[13] This is in line with this finding that, the investment levels

[13] The χ^2-test statistics are CPi: 86.05, CNi: 27.45, SPi: 2.22, SNi: 2.80, CP: 18.96, CN: 28.15, SP: 65.67, SN: 12.07 with $\chi^2(0.9, 2) = 4.61$, $\chi^2(0.95, 2) = 5.99$, and $\chi^2(0.99, 2) = 9.21$.

in these two treatments are not significantly different from the predicted equilibrium investment choice.

Table 5: Observed distribution of outcomes of the first stage

	Number of Successful Firms							
Treatment	0		1		2		Total	
CPi	32	10.67%	140	46.67%	128	42.67%	300	100%
CP	100	23.81%	210	50.00%	110	26.19%	420	100%
CNi	24	13.33%	96	53.33%	60	33.33%	180	100%
CN	74	19.27%	204	53.13%	106	27.60%	384	100%
SPi	84	29.17%	154	53.47%	50	17.36%	288	100%
SP	70	16.67%	200	47.62%	150	35.71%	420	100%
SNi	54	27.00%	108	54.00%	38	19.00%	200	100%
SN	70	26.92%	118	45.38%	72	27.69%	260	100%
Total	508	20.72%	1230	50.16%	714	29.12%	2452	100%

In the next section I focus on the observed choices in the second stage and show the connection to the outcome of the first stage.

4.2 Market Stage

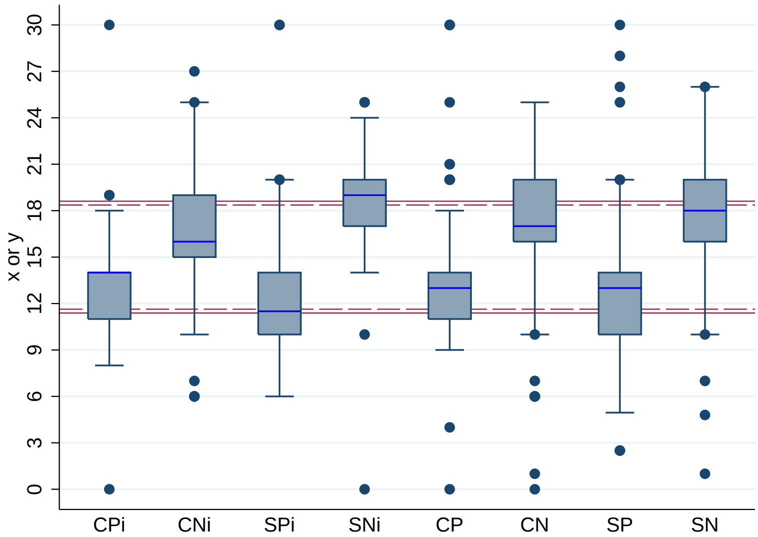
Subjects' choice in the second stage should depend on the outcome of the first stage. But before I disaggregate the data by the outcome of the first stage, I will take a brief look at the aggregate data. Figure 5 depicts boxplots of the observed second stage choices.[14] The mass of the data is distributed similarly within the positive and negative externality treatments. But the median values are rather different, i.e., within the positive externality treatments they vary between 11.5 (SPi) and 14 (CPi), and within the negative externality treatments they vary between 16 (CNi) and 19 (SNi). If one recalculates the x-choice from the y-choice, i.e., subtracts the y-choice from $m = 30$, one sees that the median values differ at most by one between the positive and the negative externality treatment. In the following I denote the recalculated x-choice by x' ($x' = m - y$).

As mentioned, the choices of x and y depend on the outcome of the first stage and the observed averages of those choices depend in addition on the distribution of outcomes of the first stage. Therefore I will analyze the data separately for each outcome of the first stage. I denote the outcome under consideration in parentheses after the treatment, e.g., CP(0) stands for the data of the CP treatment and the case of no successful firm or subject[15].

[14] The distribution of the observed x and y is presented in Figure 8 in Appendix A.1.

[15] The expressions “firm” and “subject” are interchangeably used in the following analysis, but I want to point out that the expression “firm” is not used in the instructions.

Figure 5: Boxplots of observed market stage choices



Two-sided Mann-Whitney-U tests reveal that the null hypothesis of no differences between the information and the corresponding no-k-information treatment can only be rejected in three of twelve cases. The difference is significant between CPi(0) and CP(0), CPi(1) and CP(1), and between SPi(1) and SP(1).[16] Using x' to test for differences between the corresponding positive and negative externality treatment shows that there are significant differences between CP(0) and CN(0), SPi(0) and SNi(0), and CP(1) and CN(1). Interestingly, there are no significant differences with respect to the externality and the information condition if both firms are successful. Addressing the strategic relation, the null hypothesis of no differences cannot be rejected if none of the firms has been successful.[17]

4.2.1 Deviations from x_i^* and y_i^*

The gray line in Figure 6 corresponds to the average x or y which should be observed if subjects make their choices in line with the equilibrium prediction in the according subgame. Since the distribution of first stage outcome differs from period to period the average equilibrium x or y differs as well. So far I have shown that there are differences in the second stage choices between the treatments and the effect of the

[16] The p-values are p=0.048(CPi(0) vs. CP(0)), p=0.003 (CPi(1) vs. CP(1)), and p=0.035 (SPi(1) vs. SP(1)).

[17] For the cases of at least one successful firms, I use one-sided Mann-Whitney-U tests since the theoretical predictions are not equal. There I find significant differences between CPi(1) and SPi(1) with p=0.009, CP(1,2) and SP(1,2) with p=0.012 and p=0.045, and CNi(1,2) and SNi(1,2) with p=0.071 and p=0.089.

treatment condition seems to depend on the outcome of the first stage. But this does not necessarily imply that the equilibrium predictions perform well. The median choices depicted in Figure 5 seem to be quite close to the expected aggregate equilibrium choices (indicated by solid lines (strategic substitutes) and dashed lines (strategic complements); the lower lines correspond to the positive externality and the upper ones to the negative externality treatments) in some of the treatments. Also Figure 6 reveals that there are differences between the observed and predicted aggregate equilibrium choices. The observed average x-choices are above the expected equilibrium x^* (solid line at 11.63 in the strategic complements and at 11.39 in the strategic substitutes treatments) and the average y-choices are below the expected equilibrium y^* (solid line at 18.37 in the strategic complements and at 18.61 in the strategic substitutes treatments) in almost all periods. The average deviation from the equilibrium choice in the positive externality treatments varies between 4.18% and 13.76% and in the negative externality treatments between -8.31% and -1.06% (see Table 10 in Appendix A.2).

Running OLS regressions on the difference between the observed choice and the predicted choice allows me to test whether the deviations are significant, i.e., in that case the coefficient of the constant will be significantly different from zero.

$$\Delta x_{i,t} = x_{i,t} - x^*_{i,t} = \alpha + \epsilon_{i,t} \text{ or} \quad (13)$$
$$\Delta y_{i,t} = y_{i,t} - y^*_{i,t} = \alpha + \epsilon_{i,t} \quad (14)$$

$x^*_{i,t}$ and $y^*_{i,t}$ are the predictions presented in Table 2 for the according outcome of the first stage. The results of the regressions are reported in Table 14 in Appendix A.2. They show that the difference between the observed and predicted equilibrium choices are not significant in all four negative externality treatments and significant in all four positive externality treatments. The deviation in these treatments is positive and not significantly different between the information treatments (CPi vs. SPi, t=0.151), but strongly significant between the no-k-information treatments (CP and SP, t=2.167).

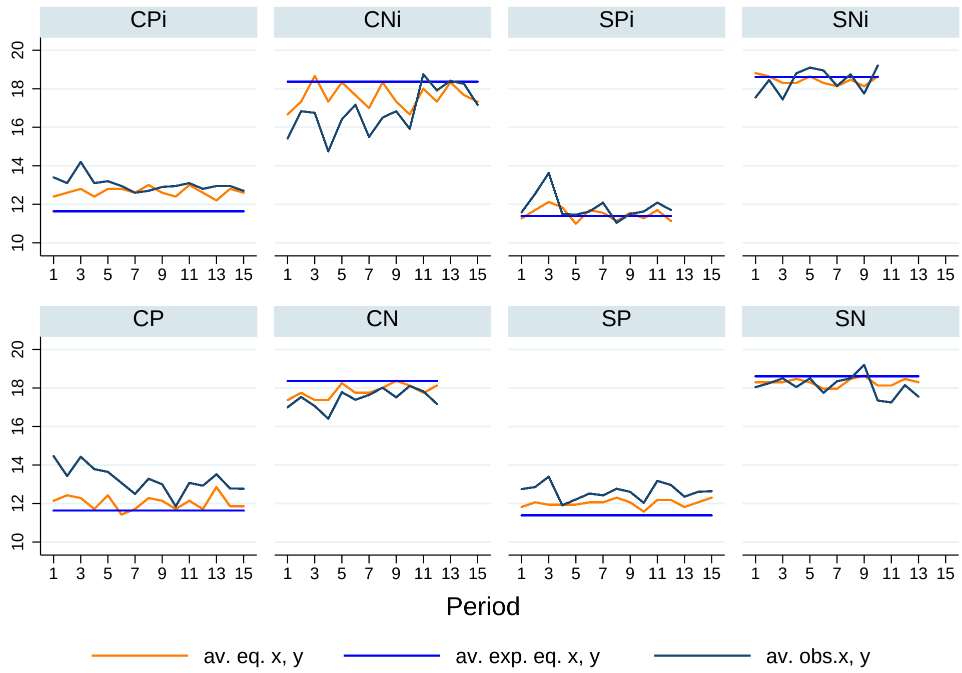
Result 4.3. *In all positive externality treatments the observed x-choices are significantly higher than predicted by theory, but in the negative externality treatment the y-choices are not significantly different from the predicted equilibrium choices. Thus, deviations from the equilibrium in the first stage can partly be explained by deviations from the equilibrium in the second stage. In three treatments (CPi, CP, and SP) I find significant deviations in both stages.*

4.2.2 Influences of the Treatment Variations on x_i- and y_i-choices

In addition to comparing the second stage choices to the equilibrium predictions, it is interesting to take a look at the development of the average choices over time. Figure

6 reveals that there are fluctuations, but overall there seems to be no substantial effect of the period in which the subjects are.

Figure 6: Time series of observed market stage choices



This observation is supported by results of OLS regressions[18]. The regression results are reported in Tables 6 and 13 in Appendix A.2 where the latter includes in addition to the former interaction terms between the different treatment variations.[19]

Being in the first half of the periods played has a significantly positive effect on the choice of x and y if no firm has been successful in the first stage and all complements treatments are considered. The effect is also significantly positive if one firm has been successful and the positive externality or the no-k-information treatments are analyzed. In case of two successful firms the effect is significantly negative, but only for the negative externality treatments. Thus, I do not find a systematic influence of being in the first or second half of the periods.

[18]The regressions include the same explanatory variables as the regressions used for analyzing the investment decisions (see equations (12)), $x_{i,t} = \alpha + \beta_1 \text{ firsthalf}_{i,t} + \beta_2 \text{ information}_{i,t} + \beta_3 \text{ posext}_{i,t} + \epsilon_{i,t}$ with the second and third term being dummy variables for the two varying treatment conditions, depending of the subset of the data one of them is exchanged with the dummy for being in a strategic substitutes treatment. The same regressions are run with $y_{i,t}$ as the dependent variable.

[19]The regression equation includes then in addition $\beta_4\text{subst\_posext}_{i,t}$, $\beta_4\text{inf\_posext}_{i,t}$, or $\beta_4\text{inf\_subst}_{i,t}$ depending on the data under consideration.

Table 6: OLS regression results on market stage choices

Number of Successful Firms: 0						
$x_{i,t}$ or $y_{i,t}$	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)
firsthalf	0.228	0.367	-0.062	0.781***	0.401	0.137
	(0.311)	(0.232)	(0.217)	(0.256)	(0.245)	(0.267)
posext	-8.938***	-8.064***	-9.334***	-7.276***		
	(0.508)	(0.520)	(0.464)	(0.393)		
substitutes	0.669	-0.461			-0.937*	0.985*
	(0.544)	(0.555)			(0.470)	(0.498)
information			0.015	-1.230**	-0.609	-0.211
			(0.446)	(0.466)	(0.409)	(0.578)
Constant	19.101***	19.748***	20.130***	19.104***	11.862***	19.144***
	(0.655)	(0.352)	(0.433)	(0.239)	(0.337)	(0.272)
R^2	0.796	0.707	0.835	0.637	0.069	0.040
N	194	314	278	230	286	222
No. of clusters	19	27	23	23	25	21
Number of Successful Firms: 1						
$x_{i,t}$ or $y_{i,t}$	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)
firsthalf	-0.125	0.340**	0.241	0.045	0.442***	-0.217
	(0.177)	(0.165)	(0.161)	(0.193)	(0.106)	(0.221)
posext	-6.026***	-5.159***	-6.077***	-5.040***		
	(0.258)	(0.250)	(0.262)	(0.224)		
substitutes	0.034	-0.366			-0.614***	0.353
	(0.238)	(0.245)			(0.166)	(0.292)
information			-0.167	-0.520**	-0.677***	0.092
			(0.241)	(0.204)	(0.154)	(0.285)
Constant	17.974***	17.756***	18.014***	17.832***	12.672***	17.756***
	(0.243)	(0.232)	(0.268)	(0.231)	(0.136)	(0.243)
R^2	0.588	0.483	0.545	0.505	0.037	0.006
N	498	732	580	650	704	526
No. of clusters	19	27	23	23	25	21
Number of Successful Firms: 2						
$x_{i,t}$ or $y_{i,t}$	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)
firsthalf	-0.455	-0.208	-0.350	-0.159	0.163	-0.909**
	(0.484)	(0.243)	(0.312)	(0.336)	(0.272)	(0.370)
posext	-0.955*	-1.740***	-2.463***	-0.678		
	(0.457)	(0.454)	(0.311)	(0.432)		
substitutes	0.339	-0.004			-0.568	1.058**
	(0.504)	(0.410)			(0.374)	(0.390)
information			0.053	-0.306	0.051	-0.556
			(0.464)	(0.407)	(0.406)	(0.457)
Constant	15.592***	16.134***	16.685***	15.567***	14.549***	16.091***
	(0.393)	(0.452)	(0.325)	(0.458)	(0.371)	(0.456)
R^2	0.035	0.089	0.151	0.020	0.015	0.058
N	276	438	310	404	438	276
No. of clusters	19	26	22	23	25	20
Data from:	CPi, CNi, SPi, SNi	CP, CN, SP, SN	SPi, SP, SNi, SN	CPi, CP, CNi, CN	CPi, CP, SPi, SP	CNi, CN, SNi, SN

Standard errors in parentheses are corrected for matching group clusters
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Being in the positive externality treatment significantly decreases the second stage choice. The coefficients are relatively close to the predicted ones (see Table 7 for the predictions). Only in case of two successful firms the effect is not significant for the complements treatments. The effect of changing the strategic relation is significant as well. In case of no successful firm the effect is weakly significant and negative for the positive externality treatments, but positive for the negative externality treatments, even though the predicted effect is zero. If one firm has been successful, the effect is significantly negative, as predicted, but only for the positive externality treatments. Considering the negative externality treatments the effect is positive, as expected, but only significant if both firms have been successful. The interaction effect of being in the SPi or SP treatment is significant and independent of the

outcome of the first stage. The impact of the information condition is negative in the positive externality treatments, but not if two firms have been successful.
The regression result corroborate the results of the non-parametric tests that the effect of the treatment conditions depends on the outcome of the first stage.

Table 7: Predicted regression coefficients

Number of Successful Firms	$x_i(SP, SPi)$ $-y_i(SN, SNi)$	$x_i(CP, CPi)$ $-y_i(CN, CNi)$	$x_i(SP, SPi)$ $-x_i(CP, CPi)$	$y_i(SN, SNi)$ $-y_i(CN, CNi)$
0	-10	-10	0	0
1	-6.6	-6	-0.3	0.3
2	-3.2	-2	-0.6	0.6

The equilibrium values of x_i and y_i are taken from Table 2.

I varied the treatments with respect to the provided information, because I surmised that the first stage choice could serve as a signaling device, e.g., a high first stage choice signals a high second stage choice. Testing for correlation between the first and second stage choices for subjects being not successful in the first stage shows that the correlation is low, but positive ($\rho = 0.0975$) and significant at the 5% level (p=0.0401) in the information treatments and that there is no significant correlation in the no-k-information treatments. Thus in treatments in which the investment choice can be observed a relatively large (small) investment, on average, corresponds to a relatively large (small) choice in the second stage. Further, I find a significantly positive correlation between the other subject's investment and the own choice of x' ($\rho = 0.1147$, p=0.0707) in the information treatments, if the own investment was successful and the one of the other firm not.

Result 4.4. *Being in the first half of the periods and being in an information treatment plays a significant role in some of the treatments, depending on the outcome of the first stage. The effect of the treatment conditions with respect to the sign of the externality and the strategic relation are significant and roughly equal the predicted effects.*

4.2.3 The Strategic Effect of Investment

A strategic investment incentive can only be present if the other subject's investment or the outcome of the investment respectively is taken into account in making the decision in the second stage. The predicted influence of b_i and b_j or β_i and β_j on x_i and x_j and on y_i and y_j is as as follows:

$$x_i(b_i, b_j) = 1.839b_i + 0.273b_j \text{ and } y_i(b_i, b_j) = 30 - 1.839b_i - 0.273b_j \quad (15)$$

$$x_i(\beta_i, \beta_j) = 1.839\beta_i - 0.273\beta_j \text{ and } y_i(\beta_i, \beta_j) = 30 - 1.839\beta_i + 0.273\beta_j. \quad (16)$$

To test whether the parameters correspond to the predictions, I regress the second stage choice on b_i and b_j or β_i and β_j respectively using OLS regressions. The results, reported in Table 15 in Appendix A.2, reveal that the own parameter b_i or β_i has a significantly positive impact on the market stage choice in all treatments, but the b_j or β_j parameter has no influence in neither treatment.[20] The sign of the coefficient of b_i or β_i is as expected and also its size is relatively close to the prediction of 1.839.

Pooling the data of the according information and no-k-information treatment and controlling for the effect of being in the information treatment and in the first half of the periods played (see Table 8 for the regression results) supports the findings of the regressions per treatment. The effect of the own parameter is significant in all treatments, but only in the negative externality and strategic complements treatment, the effect of the other subject's parameter is significant as well. The effects are in sign as expected and also the size fits the prediction relatively well. In addition the controls for being in the first half of the periods or being in an information treatment are significant in the strategic complements treatments.

These results partly corroborate the evidence that there is no significant deviation from the equilibrium prediction of the second stage choice in the negative externality treatments. The reasoning is as follows, in all but in CN and CNi subjects do not take the outcome of other subject's investment into account when making their second stage decision and thus the observed outcome has to deviate from the predicted x_i^* or y_i^*. In the CN and CNi treatment subjects do consider the outcome of the other subject's investment and even attach about the predicted weight to it, thus it is not surprising that I find no significant deviation from the predicted y_i^* in those two treatments.

5 Conclusion

In this paper I systematically investigate how strategic investment incentives perform in the laboratory. The used theoretical setup is a two-stage game where two firms make a stochastic investment in the first stage and compete in a market in the second stage. The treatments are varied with respect to three dimensions, (i) the strategic relation of the second stage choices is switched between complements and substitutes, (ii) the choice in the second stage imposes either a positive or negative externality on the other firm's profit, and (iii) the extent of information provided

[20] The regression equation is $x_{i,t} = \alpha + \beta_1 b_{i,t} + \beta_2 b_{j,t} + \epsilon_{i,t}$ for the positive externality and strategic complements treatments. The second and third term are replaced by $\beta_{i,t}$ and $\beta_{j,t}$ for the strategic substitutes treatments and the dependent variable is $y_{i,t}$ for the negative externality treatments.

Table 8: The effect of b_i, β_i, b_j, and β_j on x_i and y_i

$x_{i,t}$	Model (1)	Model (2)	Model (3)	Model (4)
b_i or β_i	1.610***	-1.820***	1.626***	-1.526***
	(0.141)	(0.142)	(0.125)	(0.163)
b_j or β_j	0.050	-0.180**	-0.116	-0.119
	(0.107)	(0.080)	(0.077)	(0.134)
information	-0.661**	-0.412	-0.248	0.152
	(0.252)	(0.476)	(0.256)	(0.306)
firsthalf	0.590***	-0.525*	0.084	-0.129
	(0.147)	(0.284)	(0.164)	(0.197)
Constant	3.493**	29.236***	0.986	30.478***
	(1.291)	(0.907)	(1.536)	(1.964)
R^2	0.321	0.314	0.387	0.330
N	720	564	708	460
No. of clusters	12	11	13	10
Data from	CPi, CP	CNi, CN	SPi, SP	SNi, SN

Standard errors in parentheses are corrected for matching group clusters.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

to the subjects is varied. All three conditions are chosen such that they have no influence on the subgame perfect Nash equilibrium investment in the first stage. The equilibrium in the second stage varies with the first two treatment conditions, depending on the outcome of the first stage. The third treatment variation has no influence on the equilibrium choices in the second stage.

Summarizing the main results, concerning the first stage choice I find that subjects overinvest with respect to the predicted equilibrium in all strategic complements treatments, independent of the externality and the information condition as well as in the strategic substitutes treatment with positive externality and without additional information provision. In the second stage I observe significantly positive deviations from the predicted equilibrium choice of the according subgame for all positive externality treatments, independent of the strategic relation and the information condition. Most interestingly, I can show that in all but the strategic complements treatments with negative externality, subjects do only take the outcome of their own first stage choice into account and not the one of the other subject when making their decision in the second stage. Using the logic of backward induction, this result suggests that a strategic investment incentive cannot exist in the strategic substitutes treatments and strategic complements with positive externality treatments. In line with this conclusion are the non-significant deviations from the predicted equilibrium investment induced by the direct investment incentive in the strategic substitutes with negative externality treatments and the strategic substitutes treatment with positive externality and information provision. In the other five treatments subjects overinvest significantly compared to the equilibrium prediction. Hence, subjects seem to overestimate the strategic investment incentive in the strategic complements treatments.

Furthermore the results show that the information condition plays a role for decision making in the first and second stage. In the first stage being in an information treatment significantly decreases the investment in the substitutes treatments, but significantly increases the investment in the strategic complements treatments. In the second stage the effect of the information condition depends on the outcome of the first stage. The results on overinvestment compared to the investment predicted in equilibrium corroborate earlier findings, e.g., in Chapter 2 we find significant overinvestment in the Bertrand, but not in the Cournot treatments.

This paper has shown that the presence of strategic investment incentives in a two-stage game with a soft investment in the first stage depends on the strategic relation between the choice variables and on the externality framing in the second stage. For further research it would be interesting to investigate whether the results are robust to a change of the strategic relation between the first and second stage choices. This additional variation could be achieved within the proposed theoretical framework by implementing a "tough" investment.

Acknowledgements

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Appendix

A.1 Figures

Figure 7: Histogram of observed investments by treatment

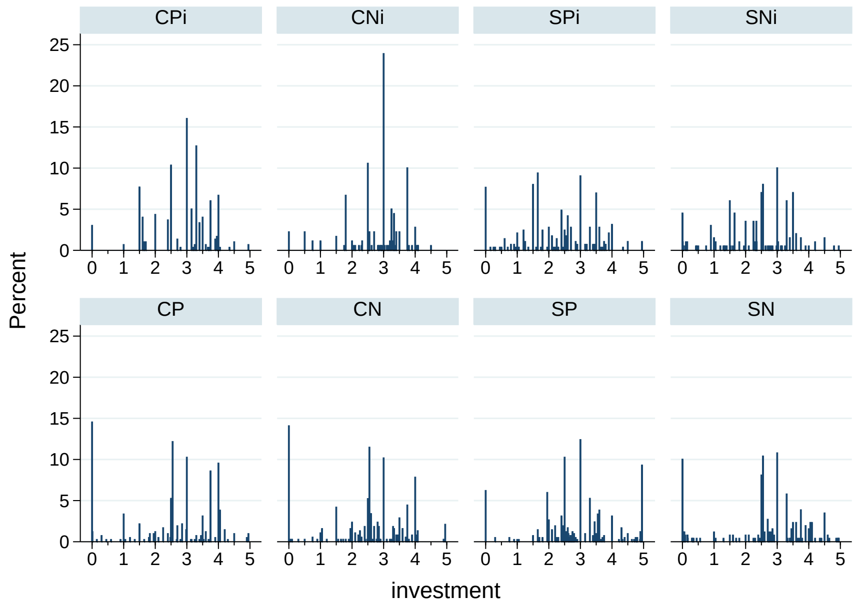
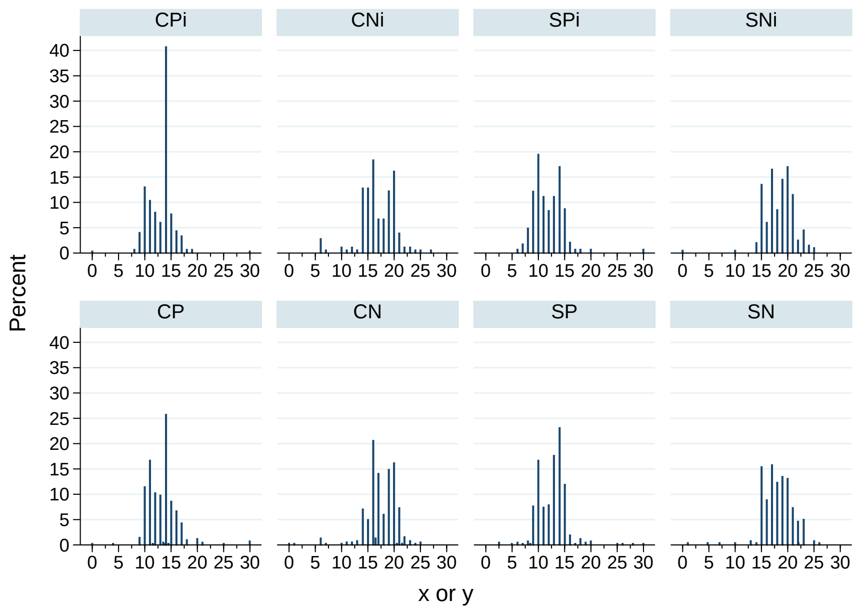


Figure 8: Histogram of observed x- and y-choices by treatment



A.2 Tables

Table 9: Number of subjects and average earnings by treatment

Treatment	No. of Subjects[1]	Av. Earnings in CHF	No. of Periods Played
CPi	20 (5)	33.01	15
CNi	12 (3)	32.92	12
SPi	24 (6)	31.84	12
SNi	20 (5)	31.55	10
CP	28 (7)	32.77	15
CN	32 (8)	32.24	12
SP	28 (7)	32.33	15
SN	20 (5)	31.94	13

[1] The number in parentheses indicated the number of matching groups and thereby the number of independent observations used for the non-parametric tests.

Table 10: Deviations from eq. investment and eq. market stage choices

					Dev. from x^*, y^* by Number of Successful Firms			
Treatment	Mean k	Dev. from k^*	Mean x, y	Dev. from x^*, y^*	0	1	2	Dev. from $x^*\|(b_i, b_j)$
CPi	2.86	39.80%	13.04	12.08%	8.75%	1.43%	3.79%	3.16%
CNi	2.79	36.37%	16.84	-8.31%	-7.92%	-2.72%	-5.42%	-4.32%
SPi	2.28	11.51%	11.86	4.18%	6.90%	-0.37%	8.07%	3.18%
SNi	2.31	13.03%	18.42	-1.06%	1.30%	0.08%	-3.15%	-0.12%
CP	2.51	22.65%	13.24	13.76%	22.40%	7.46%	5.65%	9.86%
CN	2.44	19.55%	17.45	-4.96%	-3.04%	-1.28%	-3.15%	-2.12%
SP	2.93	43.44%	12.62	10.77%	8.79%	4.58%	3.99%	4.93%
SN	2.49	22.09%	18.11	-2.69%	-0.07%	-2.71%	1.13%	-0.97%

Table 11: OLS regression results for the difference between observed and predicted investment

	(CPi) $\Delta k_{i,t}$	(CNi) $\Delta k_{i,t}$	(SPi) $\Delta k_{i,t}$	(SNi) $\Delta k_{i,t}$	(CP) $\Delta k_{i,t}$	(CN) $\Delta k_{i,t}$	(SP) $\Delta k_{i,t}$	(SN) $\Delta k_{i,t}$
Constant	0.813***	0.743*	0.235	0.266	0.463**	0.399**	0.887***	0.451
	(0.063)	(0.213)	(0.141)	(0.200)	(0.156)	(0.144)	(0.183)	(0.431)
N	300	180	288	200	420	384	420	260
No. of clusters	5	3	6	5	7	8	7	5

Standard errors in parentheses are corrected for matching group clusters.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 12: OLS regression results for the difference between observed and predicted non-strategic investment

	(CPi) $\Delta k_{i,t}^{over}$	(CNi) $\Delta k_{i,t}^{over}$	(SPi) $\Delta k_{i,t}^{under}$	(SNi) $\Delta k_{i,t}^{under}$	(CP) $\Delta k_{i,t}^{over}$	(CN) $\Delta k_{i,t}^{over}$	(SP) $\Delta k_{i,t}^{under}$	(SN) $\Delta k_{i,t}^{under}$
Constant	1.044***	0.975**	0.216	0.247	0.694***	0.631***	0.868***	0.432
	(0.063)	(0.213)	(0.141)	(0.200)	(0.156)	(0.144)	(0.183)	(0.431)
N	300	180	288	200	420	384	420	260
No. of clusters	5	3	6	5	7	8	7	5

Standard errors in parentheses are corrected for matching group clusters.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 13: OLS regression results on market stage choices II

Number of Successful Firms: 0						
$x_{i,t}$ or $y_{i,t}$	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)
firsthalf	0.226	0.349	-0.086	0.772***	0.413	0.158
	(0.282)	(0.239)	(0.210)	(0.263)	(0.255)	(0.257)
posext	-7.509***	-7.186***	-9.104***	-7.226***		
	(0.907)	(0.427)	(0.782)	(0.434)		
substitutes	1.849*	0.576			-1.367**	0.586
	(0.964)	(0.593)			(0.662)	(0.598)
information			0.281	-1.113	-1.339**	-1.004
			(0.777)	(0.832)	(0.522)	(0.851)
subst_posext	-2.026*	-1.943**				
	(1.023)	(0.886)				
inf_posext			-0.478	-0.203		
			(0.946)	(0.988)		
inf_subst					1.196	1.261
					(0.749)	(1.136)
Constant	18.285***	19.251***	20.026***	19.080***	12.034***	19.328***
	(0.890)	(0.197)	(0.555)	(0.206)	(0.390)	(0.213)
R^2	0.804	0.717	0.836	0.638	0.081	0.054
N	194	314	278	230	286	222
No. of clusters	19	27	23	23	25	21
Number of Successful Firms: 1						
$x_{i,t}$ or $y_{i,t}$	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)
firsthalf	-0.139	0.346**	0.252	0.059	0.441***	-0.240
	(0.176)	(0.165)	(0.161)	(0.190)	(0.108)	(0.219)
posext	-5.326***	-4.864***	-5.571***	-4.873***		
	(0.286)	(0.295)	(0.379)	(0.295)		
substitutes	0.819**	0.043			-0.665**	0.030
	(0.371)	(0.399)			(0.267)	(0.406)
information			0.499	-0.254	-0.740***	-0.280
			(0.408)	(0.369)	(0.188)	(0.367)
subst_posext	-1.326***	-0.707				
	(0.400)	(0.478)				
inf_posext			-1.100**	-0.471		
			(0.476)	(0.410)		
inf_subst					0.123	0.799
					(0.307)	(0.546)
Constant	17.566***	17.603***	17.690***	17.741***	12.697***	17.885***
	(0.283)	(0.256)	(0.328)	(0.260)	(0.166)	(0.264)
R^2	0.595	0.485	0.550	0.506	0.037	0.012
N	498	732	580	650	704	526
No. of clusters	19	27	23	23	25	21
Number of Successful Firms: 2						
$x_{i,t}$ or $y_{i,t}$	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)
firsthalf	-0.421	-0.151	-0.380	-0.160	0.148	-0.907**
	(0.479)	(0.232)	(0.301)	(0.338)	(0.265)	(0.369)
posext	-0.636	-0.724	-2.863***	-0.725		
	(0.544)	(0.649)	(0.185)	(0.651)		
substitutes	0.898*	1.274**			-0.855**	1.174**
	(0.513)	(0.553)			(0.394)	(0.535)
information			-0.729**	-0.373	-0.257	-0.426
			(0.294)	(0.702)	(0.491)	(0.731)
subst_posext	-0.921	-2.135***				
	(0.876)	(0.676)				
inf_posext			1.302*	0.110		
			(0.727)	(0.850)		
inf_subst					0.794	-0.331
					(0.824)	(0.772)
Constant	15.358***	15.586***	16.968***	15.592***	14.721***	16.043***
	(0.402)	(0.539)	(0.184)	(0.558)	(0.395)	(0.533)
R^2	0.040	0.122	0.160	0.021	0.020	0.059
N	276	438	310	404	438	276
No. of clusters	19	26	220	23	25	20
Data from:	CPi, CNi, SPi, SNi	CP, CN, SP, SN	SPi, SP, SNi, SN	CPi, CP, CNi, CN	CPi, CP, SPi, SP	CNi, CN, SNi, SN

Standard errors in parentheses are corrected for matching group clusters
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 14: Difference between observed and predicted market stage choices

	(CPi) $\Delta x_{i,t}$	(CNi) $\Delta y_{i,t}$	(SPi) $\Delta x_{i,t}$	(SNi) $\Delta y_{i,t}$	(CP) $\Delta x_{i,t}$	(CN) $\Delta y_{i,t}$	(SP) $\Delta x_{i,t}$	(SN) $\Delta y_{i,t}$
Constant	0.400*	-0.761	0.366*	-0.022	1.188***	-0.379	0.593***	-0.177
	(0.166)	(0.405)	(0.151)	(0.274)	(0.228)	(0.302)	(0.153)	(0.182)
N	300	180	288	200	420	384	420	260
No. of clusters	5	3	6	5	7	8	7	5

Standard errors in parentheses are corrected for matching group clusters.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 15: Influence of b_i, b_j, β_i, and β_j on x_i and y_i

	(CPi) $x_{i,t}$	(CNi) $y_{i,t}$	(SPi) $x_{i,t}$	(SNi) $y_{i,t}$	(CP) $x_{i,t}$	(CN) $y_{i,t}$	(SP) $x_{i,t}$	(SN) $y_{i,t}$
b_i or β_i	1.960***	-1.728***	1.714***	-1.529***	1.382***	-1.892***	1.566***	-1.559***
	(0.190)	(0.242)	(0.183)	(0.105)	(0.145)	(0.167)	(0.178)	(0.297)
b_j or β_j	0.165	-0.199	-0.087	-0.385	-0.020	-0.199	-0.130	0.089
	(0.152)	(0.242)	(0.118)	(0.192)	(0.142)	(0.121)	(0.108)	(0.131)
Constant	0.322	28.157***	-0.078	32.544***	5.463***	29.499***	1.585	29.107***
	(1.974)	(2.128)	(1.927)	(2.208)	(1.380)	(1.199)	(2.143)	(2.969)
N	300	180	288	200	420	384	420	260
No. of clusters	5		6	5	7	8	7	5

Standard errors in parentheses are corrected for matching group clusters in models (1) and (3)-(8).
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

A.3 Instructions (Translation from German)

In the following, comments are denoted in *italic* and have not been part of the instructions used in the experiment.

Instructions

Welcome the today's experiment! The aim of the experiment is analyzing individual decision making. Your earnings depend on your decisions, the decisions of the other participants, and chance. During the experiment your earnings and expenditures are computed in points and are accounted for with **100 points equaling CHF 1**. At the end of the experiment your total of points are converted to CHF and payed to you cash. The payment is **anonymous**. None of the other participants receives any information about your payment from our side.

Please bear in mind that you are at no point in time allowed to ask questions aloud or to communicate with the other participants. Please raise your hand, if you have a question. An experimenter will then come to you and answer your question in person.

Course of events:

1. You and all other participants are reading these instructions and answer the control questions. **The instructions are identical for each participant**. The control questions are only used to make sure that all participants understood the instructions.

2. The experiment described in the instructions is conducted.

3. After the experiment you will fill out a short questionnaire and then receive your payment.

The Experiment

The experiment consists of 15 periods. You and the other participants start in the first period with the same initial endowment of 3000 points (CHF 30). In each period you and all other participants make to decisions. A profit is determined on the basis of the decisions you make in each period. The profit can be positive or negative. Your total profit in the experiment is determined by the initial endowment and the profits of each period.

At the beginning of a period all participants are randomly matched by the computer into groups of 2 participants, i.e., the composition of the group changes from period to period. Thus, your group consists of you and one other participant. You will have nothing to do with participants of other groups in the respective period. **Your identity is anonymous at any point in time during the experiment.**

1. Decision (Determination of Types)

In each period you and the other participant in your group have the possibility to make an investment. By investing you and the other participant can change its type and thereby influence your possibility of making profits in the current period. How this works, will become clear in a moment.
You make your investment decision by choosing a number between 0 and 4.95. Your investment is only known to you, i.e., the other participant in your group cannot observe your decision. **Investing causes costs of investment.** These costs are computed as follows: **costs of investment=1.2 × investment × investment**. These costs are subtracted from your profit in this period.
The amount of your investment determines the **probability** of being type A or B in the current period. At the beginning of each period all participants are of type A. The type can only be changed by an investment. It holds that: The higher your investment, the higher is your probability that you become type B. The probability that you remain type A is the converse probability of becoming type B. Hence, the lower your investment, the higher is the probability that you remain type A. The probability of becoming type B is computed as follows: **Probability of type B in %=20 × investment**.
At your seat, you find the table "Probability and Costs of Investment" *(see Table 16)* which lists the according probabilities and costs of investment for some investment levels. For example, if you decide to invest 3.75, the probability of becoming type B is 75% and the costs of investment are 16.88 points.

After you and the other participant in your group have made their investment decisions, the computer draws separately a random number between 0% and 100%. All numbers have equal probability of being drawn.

There are two possibilities:

1. Your random number is higher than your probability of becoming type B.
   In this case your type does not change, i.e., you make your 2nd decision as type A.

2. Your random number is lower than or equal to your probability of becoming type B.
   In this case your type changes to type B, i.e., you make your 2nd decision as type B.

Again, whether you make your 2nd decision as type A or B is independent of the investment of the other participant in your group. Whether you are type A or B is only determined by your own investment, the resulting probability, and chance.

Four different situations can arise:

1. You and the other participant in your group are type B.

2. You and the other participant in your group are type A.

3. You are type B and the other participant in your group is type A.

4. You are type A and the other participant in your group is type B.

Before making the 2nd decision, you will be informed about the outcome of the first decision. You are mutually informed of which type you and the other participant in your group are
The following sentence was only included in the instructions of the information treatments: In addition you and the other participant in your group are both informed about your investment decisions.

2. Decision (Choice of Number)

In decision 2 you have to choose a number between 0 and 30. The other participant chooses a number between 0 and 30 as well. Your profit depends on your chosen number and on the one of the other participant in your group. At your seat are two different tables, table A and table B which are relevant for the according type. Your profit is depicted in both tables for some combinations of your choice of number and the choice of number of the other participant in your group. Tables A and B are identical for all participants. Which of the tables are valid in the current period depends on your type. You use

1. **Table A**, if you are type A.
2. **Table B**, if you are type B.

The following tables were used: CPi and CP use Table 17 as table A and Table 18 as table B; CNi and CN use Table 19 as table A and Table 20 as table B; SPi and SP use Table 21 as table A and Table 22 as table B; and SNi and SN use Table 23 as table A and Table 24 as table B.

You can compute your profit and the profit of the other participant in your group for all possibilities of choices by using the "profit calculator" on your computer screen. There you enter a hypothetical choice for yourself and for the other participant and get shown your profit and the one of the other participant in your group.
Example: You are type B and choose the number *[P treatments: 5, N treatments: 25]* and the other participant in your group chooses *[P treatments: 20, N treatments: 10]*, then you receive *[C treatments: 56.9, S treatments: 50.1]* points; if the other participant is type B as well, he receives *[C treatments: 12.3, S treatments: 34.4]* points. Is he type A, he receives *[C treatments: -25.5, S treatments: -9]* points. In this case he would incur a loss.

Profit per Period

Your profit of a period is presented to you after the 2nd decision and is computed as follows:
- cost of investment
+ profit of the 2nd decision
= profit of the period

If the profit of the period is positive, it will be added to your current account of points; if it is negative, it will be subtracted from your initial endowment or from your current account of point respectively.

Computer Screen 1st Decision

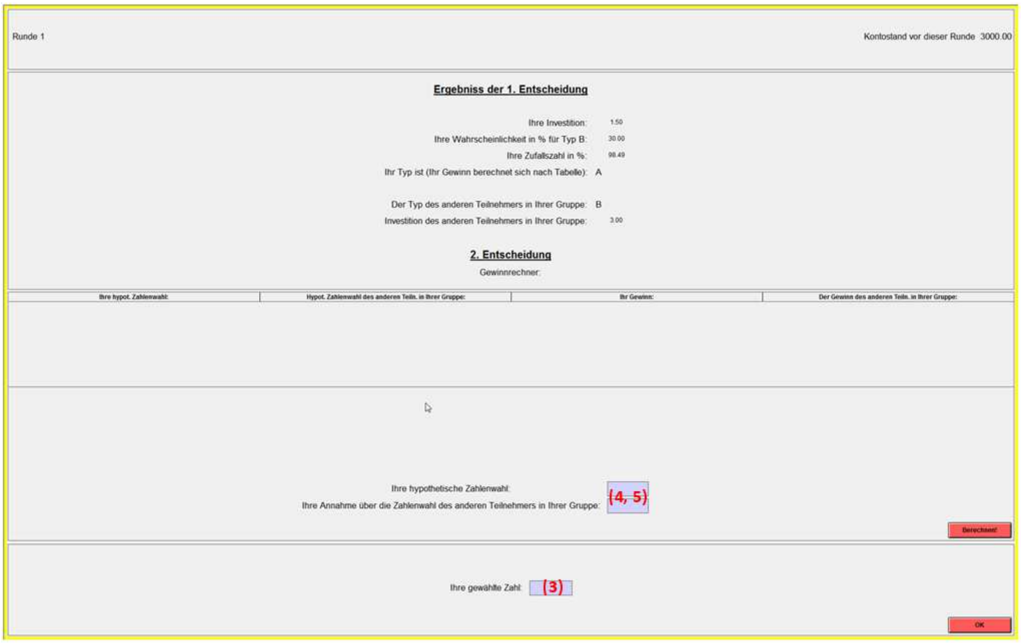
You always see this screen, if you make your first decision of a period. You can enter your

investment in field **(1)**. **All numbers between 0 and 4.95 are allowed (0, 0.01, 0.02 ... 4.93, 4.94, 4.95)**. You confirm your entry by clicking the "OK" button. You cannot change your entry afterwards and you will arrive at the second decision.

If you want to calculate your costs of investment and your probability of becoming type B before making your final entry, you can make an entry at field **(2)** and click on the "calculate!" button. You can always change this entry and let the calculation be done again.

Computer Screen 2nd Decision

You always see this screen, if you make your second decision. You can enter your chosen



number in field **(3)**. **All numbers between 0 and 30 are allowed (0, 0.01, 0.02 ... 29.98, 29.99, 30)**. You confirm your entry by clicking the “OK” button. You cannot change your entry afterwards and you will arrive first at the results of the second decision and then at the results of the period.

If you want to calculate your profit for a hypothetical choice of the other participant before making your final entry, you can make an entry in the fields **(4)** “your hypothetical choice of number” and **(5)** “your assumption about the choice of the other player” and click on the “calculate!” button. You can always change these entries and let the calculation be done again.

The information screes about the result of your 2nd decision and about the result of the period are shown to you for 10 seconds before you enter the next period. You can get earlier to the next period by clicking on the “continue” button.

Table 16: Probabilities and costs of investment

Investment	Probability for Type B in %	Costs of Investment
0	0.0%	0.00
0.15	3.0%	0.03
0.3	6.0%	0.11
0.45	9.0%	0.24
0.6	12.0%	0.43
0.75	15.0%	0.68
0.9	18.0%	0.97
1.05	21.0%	1.32
1.2	24.0%	1.73
1.35	27.0%	2.19
1.5	30.0%	2.70
1.65	33.0%	3.27
1.8	36.0%	3.89
1.95	39.0%	4.56
2.1	42.0%	5.29
2.25	45.0%	6.08
2.4	48.0%	6.91
2.55	51.0%	7.80
2.7	54.0%	8.75
2.85	57.0%	9.75
3	60.0%	10.80
3.15	63.0%	11.91
3.3	66.0%	13.07
3.45	69.0%	14.28
3.6	72.0%	15.55
3.75	75.0%	16.88
3.9	78.0%	18.25
4.05	81.0%	19.68
4.2	84.0%	21.17
4.35	87.0%	22.71
4.5	90.0%	24.30
4.65	93.0%	25.95
4.8	96.0%	27.65
4.95	99.0%	29.40

Table 17: Payoff table A for the CP and CPi treatment

TABLE A

The choice of the other participant in my group

My choice	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
0	-30.0	-27.5	-24.9	-22.4	-19.9	-17.3	-14.7	-12.1	-9.5	-6.9	-4.3	-1.7	1.0	3.6	6.3	9.0	11.6	14.3	17.1	19.8	22.5	25.2	28.0	30.8	33.5	36.3	39.1	41.9	44.7	47.6	50.4	**0**
1	-25.5	-22.9	-20.3	-17.7	-15.1	-12.4	-9.8	-7.1	-4.4	-1.7	1.0	3.7	6.4	9.2	11.9	14.7	17.4	20.2	23.0	25.8	28.6	31.4	34.3	37.1	40.0	42.8	45.7	48.6	51.5	54.4	57.3	**1**
2	-21.6	-19.0	-16.3	-13.6	-10.8	-8.1	-5.4	-2.6	0.2	2.9	5.7	8.5	11.3	14.1	17.0	19.8	22.6	25.5	28.4	31.3	34.2	37.1	40.0	42.9	45.8	48.8	51.8	54.7	57.7	60.7	63.7	**2**
3	-18.3	-15.5	-12.8	-10.0	-7.2	-4.3	-1.5	1.3	4.2	7.0	9.9	12.8	15.6	18.5	21.5	24.4	27.3	30.3	33.2	36.2	39.2	42.1	45.1	48.2	51.2	54.2	57.2	60.3	63.4	66.4	69.5	**3**
4	-15.5	-12.7	-9.8	-6.9	-4.0	-1.1	1.8	4.7	7.6	10.5	13.5	16.5	19.4	22.4	25.4	28.4	31.4	34.4	37.5	40.5	43.6	46.7	49.7	52.8	55.9	59.1	62.2	65.3	68.5	71.6	74.8	**4**
5	-13.3	-10.3	-7.4	-4.4	-1.5	1.5	4.5	7.5	10.5	13.5	16.6	19.6	22.6	25.7	28.8	31.9	35.0	38.1	41.2	44.3	47.5	50.6	53.8	57.0	60.2	63.4	66.6	69.8	73.0	76.2	79.5	**5**
6	-11.6	-8.6	-5.6	-2.5	0.5	3.6	6.7	9.7	12.8	15.9	19.1	22.2	25.3	28.5	31.6	34.8	38.0	41.2	44.4	47.6	50.8	54.0	57.3	60.5	63.8	67.1	70.4	73.7	77.0	80.3	83.7	**6**
7	-10.5	-7.4	-4.3	-1.2	2.0	5.1	8.3	11.4	14.6	17.8	21.0	24.2	27.4	30.7	33.9	37.1	40.4	43.7	47.0	50.3	53.6	56.9	60.2	63.6	66.9	70.3	73.6	77.0	80.4	83.8	87.2	**7**
8	-9.9	-6.7	-3.5	-0.3	2.9	6.1	9.3	12.6	15.8	19.1	22.4	25.7	29.0	32.3	35.6	39.0	42.3	45.7	49.0	52.4	55.8	59.2	62.6	66.0	69.5	72.9	76.4	79.8	83.3	86.8	90.3	**8**
9	-9.9	-6.6	-3.4	-0.1	3.2	6.5	9.8	13.2	16.5	19.9	23.2	26.6	30.0	33.4	36.8	40.2	43.6	47.1	50.5	54.0	57.4	60.9	64.4	67.9	71.4	75.0	78.5	82.1	85.6	89.2	92.8	**9**
10	-10.5	-7.1	-3.7	-0.4	3.0	6.4	9.8	13.2	16.6	20.1	23.5	27.0	30.4	33.9	37.4	40.9	44.4	47.9	51.5	55.0	58.6	62.1	65.7	69.3	72.9	76.5	80.1	83.7	87.4	91.0	94.7	**10**
11	-11.6	-8.1	-4.7	-1.2	2.2	5.7	9.2	12.7	16.2	19.7	23.2	26.8	30.3	33.9	37.4	41.0	44.6	48.2	51.8	55.5	59.1	62.7	66.4	70.1	73.8	77.4	81.2	84.9	88.6	92.3	96.1	**11**
12	-13.2	-9.7	-6.2	-2.6	0.9	4.5	8.0	11.6	15.2	18.8	22.4	26.0	29.6	33.3	36.9	40.6	44.3	48.0	51.7	55.4	59.1	62.8	66.6	70.3	74.1	77.9	81.6	85.4	89.2	93.1	96.9	**12**
13	-15.4	-11.8	-8.2	-4.6	-1.0	2.6	6.3	10.0	13.6	17.3	21.0	24.7	28.4	32.1	35.9	39.6	43.4	47.2	50.9	54.7	58.5	62.3	66.2	70.0	73.8	77.7	81.6	85.4	89.3	93.2	97.1	**13**
14	-18.2	-14.5	-10.8	-7.1	-3.4	0.3	4.0	7.8	11.5	15.3	19.1	22.8	26.6	30.4	34.3	38.1	41.9	45.8	49.6	53.5	57.4	61.3	65.2	69.1	73.1	77.0	80.9	84.9	88.9	92.9	96.9	**14**
15	-21.5	-17.8	-14.0	-10.2	-6.4	-2.6	1.2	5.0	8.8	12.7	16.6	20.4	24.3	28.2	32.1	36.0	39.9	43.9	47.8	51.8	55.7	59.7	63.7	67.7	71.7	75.7	79.8	83.8	87.9	91.9	96.0	**15**
16	-25.4	-21.6	-17.7	-13.9	-10.0	-6.1	-2.2	1.7	5.6	9.6	13.5	17.4	21.4	25.4	29.4	33.4	37.4	41.4	45.4	49.4	53.5	57.6	61.6	65.7	69.8	73.9	78.0	82.1	86.3	90.4	94.6	**16**
17	-29.8	-25.9	-22.0	-18.0	-14.1	-10.1	-6.1	-2.2	1.8	5.9	9.9	13.9	18.0	22.0	26.1	30.2	34.2	38.3	42.5	46.6	50.7	54.8	59.0	63.2	67.3	71.5	75.7	79.9	84.2	88.4	92.6	**17**
18	-34.8	-30.8	-26.8	-22.8	-18.8	-14.7	-10.6	-6.6	-2.5	1.6	5.7	9.8	14.0	18.1	22.2	26.4	30.6	34.7	38.9	43.1	47.4	51.6	55.8	60.1	64.3	68.6	72.9	77.2	81.5	85.8	90.1	**18**
19	-40.4	-36.3	-32.2	-28.1	-24.0	-19.8	-15.7	-11.5	-7.4	-3.2	1.0	5.2	9.4	13.6	17.8	22.1	26.3	30.6	34.9	39.2	43.5	47.8	52.1	56.4	60.8	65.1	69.5	73.8	78.2	82.6	87.0	**19**
20	-46.5	-42.3	-38.1	-34.0	-29.8	-25.5	-21.3	-17.1	-12.8	-8.6	-4.3	0.0	4.3	8.6	12.9	17.2	21.5	25.9	30.3	34.6	39.0	43.4	47.8	52.2	56.6	61.1	65.5	70.0	74.4	78.9	83.4	**20**
21	-53.2	-48.9	-44.6	-40.4	-36.1	-31.8	-27.5	-23.2	-18.8	-14.5	-10.1	-5.8	-1.4	3.0	7.4	11.8	16.2	20.6	25.1	29.5	34.0	38.5	42.9	47.4	51.9	56.5	61.0	65.5	70.1	74.6	79.2	**21**
22	-60.4	-56.0	-51.7	-47.3	-43.0	-38.6	-34.2	-29.8	-25.4	-21.0	-16.5	-12.1	-7.6	-3.2	1.3	5.8	10.3	14.8	19.3	23.9	28.4	33.0	37.5	42.1	46.7	51.3	55.9	60.5	65.2	69.8	74.5	**22**
23	-68.2	-63.7	-59.3	-54.9	-50.4	-46.0	-41.5	-37.0	-32.5	-28.0	-23.5	-19.0	-14.4	-9.9	-5.3	-0.7	3.9	8.4	13.1	17.7	22.3	26.9	31.6	36.2	40.9	45.6	50.3	55.0	59.7	64.4	69.2	**23**
24	-76.5	-72.0	-67.5	-63.0	-58.4	-53.9	-49.3	-44.8	-40.2	-35.6	-31.0	-26.4	-21.8	-17.1	-12.5	-7.8	-3.2	1.5	6.2	10.9	15.6	20.3	25.1	29.8	34.6	39.3	44.1	48.9	53.7	58.5	63.3	**24**
25	-85.4	-80.8	-76.2	-71.6	-67.0	-62.4	-57.7	-53.1	-48.4	-43.7	-39.1	-34.4	-29.7	-24.9	-20.2	-15.5	-10.7	-6.0	-1.2	3.6	8.4	13.2	18.0	22.8	27.7	32.5	37.4	42.2	47.1	52.0	56.9	**25**
26	-94.8	-90.2	-85.5	-80.8	-76.1	-71.4	-66.7	-61.9	-57.2	-52.4	-47.7	-42.9	-38.1	-33.3	-28.5	-23.7	-18.9	-14.0	-9.2	-4.3	0.6	5.5	10.4	15.3	20.2	25.1	30.1	35.0	40.0	44.9	49.9	**26**
27	-104.8	-100.1	-95.3	-90.5	-85.8	-81.0	-76.2	-71.4	-66.5	-61.7	-56.8	-52.0	-47.1	-42.2	-37.3	-32.4	-27.5	-22.6	-17.7	-12.7	-7.8	-2.8	2.2	7.2	12.2	17.2	22.2	27.2	32.3	37.3	42.4	**27**
28	-115.4	-110.5	-105.7	-100.8	-96.0	-91.1	-86.2	-81.3	-76.4	-71.5	-66.6	-61.6	-56.7	-51.7	-46.7	-41.8	-36.8	-31.8	-26.7	-21.7	-16.7	-11.6	-6.6	-1.5	3.6	8.7	13.8	18.9	24.0	29.2	34.3	**28**
29	-126.5	-121.6	-116.6	-111.7	-106.8	-101.8	-96.8	-91.9	-86.9	-81.9	-76.9	-71.8	-66.8	-61.8	-56.7	-51.6	-46.6	-41.5	-36.4	-31.3	-26.1	-21.0	-15.9	-10.7	-5.5	-0.4	4.8	10.0	15.2	20.5	25.7	**29**
30	-138.2	-133.2	-128.1	-123.1	-118.1	-113.1	-108.0	-103.0	-97.9	-92.8	-87.7	-82.6	-77.5	-72.4	-67.2	-62.1	-56.9	-51.7	-46.5	-41.4	-36.2	-30.9	-25.7	-20.5	-15.2	-10.0	-4.7	0.6	5.9	11.2	16.5	**30**
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	

Table 18: Payoff table B for the CP and CPi treatment

TABLE B

The choice of the other participant in my group

My choice	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
0	-30.0	-27.5	-24.9	-22.4	-19.9	-17.3	-14.7	-12.1	-9.5	-6.9	-4.3	-1.7	1.0	3.6	6.3	9.0	11.6	14.3	17.1	19.8	22.5	25.2	28.0	30.8	33.5	36.3	39.1	41.9	44.7	47.6	50.4	**0**
1	-23.6	-21.0	-18.4	-15.8	-13.2	-10.5	-7.9	-5.2	-2.5	0.2	2.9	5.6	8.3	11.0	13.8	16.6	19.3	22.1	24.9	27.7	30.5	33.3	36.2	39.0	41.9	44.7	47.6	50.5	53.4	56.3	59.2	**1**
2	-17.9	-15.2	-12.5	-9.8	-7.0	-4.3	-1.6	1.2	3.9	6.7	9.5	12.3	15.1	17.9	20.7	23.6	26.4	29.3	32.2	35.1	37.9	40.9	43.8	46.7	49.6	52.6	55.5	58.5	61.5	64.5	67.5	**2**
3	-12.6	-9.8	-7.1	-4.3	-1.5	1.3	4.2	7.0	9.8	12.7	15.6	18.4	21.3	24.2	27.1	30.1	33.0	35.9	38.9	41.9	44.8	47.8	50.8	53.8	56.9	59.9	62.9	66.0	69.0	72.1	75.2	**3**
4	-7.9	-5.1	-2.2	0.7	3.5	6.4	9.3	12.3	15.2	18.1	21.1	24.0	27.0	30.0	33.0	36.0	39.0	42.0	45.1	48.1	51.2	54.2	57.3	60.4	63.5	66.6	69.8	72.9	76.0	79.2	82.4	**4**
5	-3.8	-0.9	2.1	5.0	8.0	11.0	14.0	17.0	20.0	23.0	26.0	29.1	32.1	35.2	38.3	41.3	44.4	47.6	50.7	53.8	56.9	60.1	63.3	66.4	69.6	72.8	76.0	79.2	82.5	85.7	89.0	**5**
6	-0.2	2.8	5.8	8.8	11.9	15.0	18.0	21.1	24.2	27.3	30.4	33.5	36.7	39.8	43.0	46.2	49.3	52.5	55.7	58.9	62.2	65.4	68.6	71.9	75.2	78.5	81.7	85.0	88.4	91.7	95.0	**6**
7	2.8	5.9	9.0	12.1	15.2	18.4	21.5	24.7	27.9	31.1	34.3	37.5	40.7	43.9	47.2	50.4	53.7	56.9	60.2	63.5	66.8	70.1	73.5	76.8	80.2	83.5	86.9	90.3	93.7	97.1	100.5	**7**
8	5.2	8.4	11.6	14.8	18.0	21.3	24.5	27.7	31.0	34.3	37.5	40.8	44.1	47.4	50.8	54.1	57.4	60.8	64.2	67.6	70.9	74.3	77.8	81.2	84.6	88.1	91.5	95.0	98.5	101.9	105.4	**8**
9	7.1	10.4	13.7	17.0	20.3	23.6	26.9	30.2	33.6	36.9	40.3	43.6	47.0	50.4	53.8	57.2	60.7	64.1	67.6	71.0	74.5	78.0	81.5	85.0	88.5	92.0	95.6	99.1	102.7	106.2	109.8	**9**
10	8.5	11.8	15.2	18.6	21.9	25.3	28.7	32.1	35.6	39.0	42.4	45.9	49.4	52.8	56.3	59.8	63.3	66.9	70.4	73.9	77.5	81.1	84.6	88.2	91.8	95.4	99.0	102.7	106.3	110.0	113.6	**10**
11	9.3	12.7	16.1	19.6	23.1	26.5	30.0	33.5	37.0	40.5	44.1	47.6	51.1	54.7	58.3	61.9	65.4	69.1	72.7	76.3	79.9	83.6	87.2	90.9	94.6	98.3	102.0	105.7	109.4	113.2	116.9	**11**
12	9.5	13.0	16.5	20.1	23.6	27.2	30.7	34.3	37.9	41.5	45.1	48.7	52.4	56.0	59.7	63.3	67.0	70.7	74.4	78.1	81.8	85.5	89.3	93.0	96.8	100.6	104.4	108.2	112.0	115.8	119.6	**12**
13	9.2	12.8	16.4	20.0	23.6	27.3	30.9	34.6	38.2	41.9	45.6	49.3	53.0	56.8	60.5	64.2	68.0	71.8	75.6	79.3	83.1	87.0	90.8	94.6	98.5	102.3	106.2	110.1	114.0	117.9	121.8	**13**
14	8.3	12.0	15.7	19.4	23.1	26.8	30.5	34.3	38.0	41.8	45.6	49.4	53.2	57.0	60.8	64.6	68.4	72.3	76.2	80.0	83.9	87.8	91.7	95.6	99.6	103.5	107.5	111.4	115.4	119.4	123.4	**14**
15	6.9	10.6	14.4	18.2	22.0	25.8	29.6	33.4	37.3	41.1	45.0	48.8	52.7	56.6	60.5	64.4	68.3	72.3	76.2	80.2	84.1	88.1	92.1	96.1	100.1	104.1	108.2	112.2	116.3	120.3	124.4	**15**
16	4.9	8.7	12.6	16.5	20.3	24.2	28.1	32.0	35.9	39.9	43.8	47.7	51.7	55.7	59.7	63.7	67.7	71.7	75.7	79.7	83.8	87.9	91.9	96.0	100.1	104.2	108.3	112.5	116.6	120.7	124.9	**16**
17	2.4	6.3	10.2	14.2	18.1	22.1	26.1	30.0	34.0	38.1	42.1	46.1	50.2	54.2	58.3	62.4	66.4	70.5	74.6	78.8	82.9	87.0	91.2	95.4	99.5	103.7	107.9	112.1	116.4	120.6	124.8	**17**
18	-0.8	3.3	7.3	11.3	15.3	19.4	23.4	27.5	31.6	35.7	39.8	43.9	48.0	52.2	56.3	60.5	64.7	68.8	73.0	77.2	81.5	85.7	89.9	94.2	98.4	102.7	107.0	111.3	115.6	119.9	124.2	**18**
19	-4.4	-0.3	3.8	7.9	12.0	16.1	20.3	24.4	28.6	32.8	37.0	41.2	45.4	49.6	53.8	58.1	62.3	66.6	70.9	75.1	79.4	83.8	88.1	92.4	96.7	101.1	105.5	109.8	114.2	118.6	123.0	**19**
20	-8.6	-4.4	-0.3	3.9	8.1	12.3	16.6	20.8	25.1	29.3	33.6	37.9	42.2	46.5	50.8	55.1	59.4	63.8	68.1	72.5	76.9	81.3	85.7	90.1	94.5	98.9	103.4	107.8	112.3	116.8	121.3	**20**
21	-13.4	-9.1	-4.9	-0.6	3.7	8.0	12.3	16.6	20.9	25.3	29.6	34.0	38.4	42.8	47.2	51.6	56.0	60.4	64.8	69.3	73.8	78.2	82.7	87.2	91.7	96.2	100.8	105.3	109.9	114.4	119.0	**21**
22	-18.7	-14.4	-10.0	-5.7	-1.3	3.1	7.5	11.9	16.3	20.7	25.1	29.6	34.0	38.5	43.0	47.5	52.0	56.5	61.0	65.5	70.1	74.6	79.2	83.8	88.4	93.0	97.6	102.2	106.8	111.5	116.1	**22**
23	-24.6	-20.2	-15.7	-11.3	-6.9	-2.4	2.1	6.6	11.1	15.6	20.1	24.6	29.1	33.7	38.3	42.8	47.4	52.0	56.6	61.2	65.9	70.5	75.1	79.8	84.5	89.2	93.8	98.6	103.3	108.0	112.7	**23**
24	-31.0	-26.5	-22.0	-17.5	-13.0	-8.4	-3.9	0.7	5.3	9.9	14.5	19.1	23.7	28.3	33.0	37.6	42.3	47.0	51.7	56.4	61.1	65.8	70.5	75.3	80.0	84.8	89.6	94.3	99.1	103.9	108.8	**24**
25	-38.0	-33.4	-28.8	-24.2	-19.6	-15.0	-10.4	-5.7	-1.1	3.6	8.3	13.0	17.7	22.4	27.1	31.9	36.6	41.4	46.2	50.9	55.7	60.5	65.3	70.2	75.0	79.9	84.7	89.6	94.5	99.3	104.3	**25**
26	-45.6	-40.9	-36.2	-31.5	-26.8	-22.1	-17.4	-12.7	-7.9	-3.2	1.6	6.4	11.1	15.9	20.7	25.6	30.4	35.2	40.1	45.0	49.8	54.7	59.6	64.5	69.4	74.4	79.3	84.3	89.2	94.2	99.2	**26**
27	-53.7	-48.9	-44.2	-39.4	-34.6	-29.8	-25.0	-20.2	-15.4	-10.6	-5.7	-0.8	4.0	8.9	13.8	18.7	23.6	28.5	33.5	38.4	43.4	48.3	53.3	58.3	63.3	68.3	73.3	78.4	83.4	88.5	93.5	**27**
28	-62.3	-57.5	-52.7	-47.8	-43.0	-38.1	-33.2	-28.3	-23.4	-18.5	-13.5	-8.6	-3.6	1.3	6.3	11.3	16.3	21.3	26.3	31.3	36.4	41.4	46.5	51.5	56.6	61.7	66.8	71.9	77.1	82.2	87.4	**28**
29	-71.6	-66.6	-61.7	-56.8	-51.8	-46.9	-41.9	-36.9	-31.9	-26.9	-21.9	-16.9	-11.9	-6.8	-1.8	3.3	8.4	13.5	18.6	23.7	28.8	33.9	39.1	44.2	49.4	54.6	59.8	65.0	70.2	75.4	80.6	**29**
30	-81.3	-76.3	-71.3	-66.3	-61.3	-56.2	-51.2	-46.1	-41.1	-36.0	-30.9	-25.8	-20.7	-15.5	-10.4	-5.2	-0.1	5.1	10.3	15.5	20.7	25.9	31.1	36.3	41.6	46.9	52.1	57.4	62.7	68.0	73.3	**30**
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	

Table 19: Payoff table A for the CN and CNi treatment

TABLE A

The choice of the other participant in my group (columns); My choice (rows)

My choice	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
0	16.5	11.2	5.9	0.6	-4.7	-10.0	-15.2	-20.5	-25.7	-30.9	-36.2	-41.4	-46.5	-51.7	-56.9	-62.1	-67.2	-72.4	-77.5	-82.6	-87.7	-92.8	-97.9	-103.0	-108.0	-113.1	-118.1	-123.1	-128.1	-133.2	-138.2	**0**
1	25.7	20.5	15.2	10.0	4.8	-0.4	-5.5	-10.7	-15.9	-21.0	-26.1	-31.3	-36.4	-41.5	-46.6	-51.6	-56.7	-61.8	-66.8	-71.8	-76.9	-81.9	-86.9	-91.9	-96.8	-101.8	-106.8	-111.7	-116.6	-121.6	-126.5	**1**
2	34.3	29.2	24.0	18.9	13.8	8.7	3.6	-1.5	-6.6	-11.6	-16.7	-21.7	-26.7	-31.8	-36.8	-41.8	-46.7	-51.7	-56.7	-61.6	-66.6	-71.5	-76.4	-81.3	-86.2	-91.1	-96.0	-100.8	-105.7	-110.5	-115.4	**2**
3	42.4	37.3	32.3	27.2	22.2	17.2	12.2	7.2	2.2	-2.8	-7.8	-12.7	-17.7	-22.6	-27.5	-32.4	-37.3	-42.2	-47.1	-52.0	-56.8	-61.7	-66.5	-71.4	-76.2	-81.0	-85.8	-90.5	-95.3	-100.1	-104.8	**3**
4	49.9	44.9	40.0	35.0	30.1	25.1	20.2	15.3	10.4	5.5	0.6	-4.3	-9.2	-14.0	-18.9	-23.7	-28.5	-33.3	-38.1	-42.9	-47.7	-52.4	-57.2	-61.9	-66.7	-71.4	-76.1	-80.8	-85.5	-90.2	-94.8	**4**
5	56.9	52.0	47.1	42.2	37.4	32.5	27.7	22.8	18.0	13.2	8.4	3.6	-1.2	-6.0	-10.7	-15.5	-20.2	-24.9	-29.7	-34.4	-39.1	-43.7	-48.4	-53.1	-57.7	-62.4	-67.0	-71.6	-76.2	-80.8	-85.4	**5**
6	63.3	58.5	53.7	48.9	44.1	39.3	34.6	29.8	25.1	20.3	15.6	10.9	6.2	1.5	-3.2	-7.8	-12.5	-17.1	-21.8	-26.4	-31.0	-35.6	-40.2	-44.8	-49.3	-53.9	-58.4	-63.0	-67.5	-72.0	-76.5	**6**
7	69.2	64.4	59.7	55.0	50.3	45.6	40.9	36.2	31.6	26.9	22.3	17.7	13.1	8.4	3.9	-0.7	-5.3	-9.9	-14.4	-19.0	-23.5	-28.0	-32.5	-37.0	-41.5	-46.0	-50.4	-54.9	-59.3	-63.7	-68.2	**7**
8	74.5	69.8	65.2	60.5	55.9	51.3	46.7	42.1	37.5	33.0	28.4	23.9	19.3	14.8	10.3	5.8	1.3	-3.2	-7.6	-12.1	-16.5	-21.0	-25.4	-29.8	-34.2	-38.6	-43.0	-47.3	-51.7	-56.0	-60.4	**8**
9	79.2	74.6	70.1	65.5	61.0	56.5	51.9	47.4	42.9	38.5	34.0	29.5	25.1	20.6	16.2	11.8	7.4	3.0	-1.4	-5.8	-10.1	-14.5	-18.8	-23.2	-27.5	-31.8	-36.1	-40.4	-44.6	-48.9	-53.2	**9**
10	83.4	78.9	74.4	70.0	65.5	61.1	56.6	52.2	47.8	43.4	39.0	34.6	30.3	25.9	21.5	17.2	12.9	8.6	4.3	0.0	-4.3	-8.6	-12.8	-17.1	-21.3	-25.5	-29.8	-34.0	-38.1	-42.3	-46.5	**10**
11	87.0	82.6	78.2	73.8	69.5	65.1	60.8	56.4	52.1	47.8	43.5	39.2	34.9	30.6	26.3	22.1	17.8	13.6	9.4	5.2	1.0	-3.2	-7.4	-11.5	-15.7	-19.8	-24.0	-28.1	-32.2	-36.3	-40.4	**11**
12	90.1	85.8	81.5	77.2	72.9	68.6	64.3	60.1	55.8	51.6	47.4	43.1	38.9	34.7	30.6	26.4	22.2	18.1	14.0	9.8	5.7	1.6	-2.5	-6.6	-10.6	-14.7	-18.8	-22.8	-26.8	-30.8	-34.8	**12**
13	92.6	88.4	84.2	79.9	75.7	71.5	67.3	63.2	59.0	54.8	50.7	46.6	42.5	38.3	34.2	30.2	26.1	22.0	18.0	13.9	9.9	5.9	1.8	-2.2	-6.1	-10.1	-14.1	-18.0	-22.0	-25.9	-29.8	**13**
14	94.6	90.4	86.3	82.1	78.0	73.9	69.8	65.7	61.6	57.6	53.5	49.4	45.4	41.4	37.4	33.4	29.4	25.4	21.4	17.4	13.5	9.6	5.6	1.7	-2.2	-6.1	-10.0	-13.9	-17.7	-21.6	-25.4	**14**
15	96.0	91.9	87.9	83.8	79.8	75.7	71.7	67.7	63.7	59.7	55.7	51.8	47.8	43.9	39.9	36.0	32.1	28.2	24.3	20.4	16.6	12.7	8.8	5.0	1.2	-2.6	-6.4	-10.2	-14.0	-17.8	-21.5	**15**
16	96.9	92.9	88.9	84.9	80.9	77.0	73.1	69.1	65.2	61.3	57.4	53.5	49.6	45.8	41.9	38.1	34.3	30.4	26.6	22.8	19.1	15.3	11.5	7.8	4.0	0.3	-3.4	-7.1	-10.8	-14.5	-18.2	**16**
17	97.1	93.2	89.3	85.4	81.6	77.7	73.8	70.0	66.2	62.3	58.5	54.7	50.9	47.2	43.4	39.6	35.9	32.1	28.4	24.7	21.0	17.3	13.6	10.0	6.3	2.6	-1.0	-4.6	-8.2	-11.8	-15.4	**17**
18	96.9	93.1	89.2	85.4	81.6	77.9	74.1	70.3	66.6	62.8	59.1	55.4	51.7	48.0	44.3	40.6	36.9	33.3	29.6	26.0	22.4	18.8	15.2	11.6	8.0	4.5	0.9	-2.6	-6.2	-9.7	-13.2	**18**
19	96.1	92.3	88.6	84.9	81.2	77.4	73.8	70.1	66.4	62.7	59.1	55.5	51.8	48.2	44.6	41.0	37.4	33.9	30.3	26.8	23.2	19.7	16.2	12.7	9.2	5.7	2.2	-1.2	-4.7	-8.1	-11.6	**19**
20	94.7	91.0	87.4	83.7	80.1	76.5	72.9	69.3	65.7	62.1	58.6	55.0	51.5	47.9	44.4	40.9	37.4	33.9	30.4	27.0	23.5	20.1	16.6	13.2	9.8	6.4	3.0	-0.4	-3.7	-7.1	-10.5	**20**
21	92.8	89.2	85.6	82.1	78.5	75.0	71.4	67.9	64.4	60.9	57.4	54.0	50.5	47.1	43.6	40.2	36.8	33.4	30.0	26.6	23.2	19.9	16.5	13.2	9.8	6.5	3.2	-0.1	-3.4	-6.6	-9.9	**21**
22	90.3	86.8	83.3	79.8	76.4	72.9	69.5	66.0	62.6	59.2	55.8	52.4	49.0	45.7	42.3	39.0	35.6	32.3	29.0	25.7	22.4	19.1	15.8	12.6	9.3	6.1	2.9	-0.3	-3.5	-6.7	-9.9	**22**
23	87.2	83.8	80.4	77.0	73.6	70.3	66.9	63.6	60.2	56.9	53.6	50.3	47.0	43.7	40.4	37.1	33.9	30.7	27.4	24.2	21.0	17.8	14.6	11.4	8.3	5.1	2.0	-1.2	-4.3	-7.4	-10.5	**23**
24	83.7	80.3	77.0	73.7	70.4	67.1	63.8	60.5	57.3	54.0	50.8	47.6	44.4	41.2	38.0	34.8	31.6	28.5	25.3	22.2	19.1	15.9	12.8	9.7	6.7	3.6	0.5	-2.5	-5.6	-8.6	-11.6	**24**
25	79.5	76.2	73.0	69.8	66.6	63.4	60.2	57.0	53.8	50.6	47.5	44.3	41.2	38.1	35.0	31.9	28.8	25.7	22.6	19.6	16.6	13.5	10.5	7.5	4.5	1.5	-1.5	-4.4	-7.4	-10.3	-13.3	**25**
26	74.8	71.6	68.5	65.3	62.2	59.1	55.9	52.8	49.7	46.7	43.6	40.5	37.5	34.4	31.4	28.4	25.4	22.4	19.4	16.5	13.5	10.5	7.6	4.7	1.8	-1.1	-4.0	-6.9	-9.8	-12.7	-15.5	**26**
27	69.5	66.4	63.4	60.3	57.2	54.2	51.2	48.2	45.1	42.1	39.2	36.2	33.2	30.3	27.3	24.4	21.5	18.5	15.6	12.8	9.9	7.0	4.2	1.3	-1.5	-4.3	-7.2	-10.0	-12.8	-15.5	-18.3	**27**
28	63.7	60.7	57.7	54.7	51.8	48.8	45.8	42.9	40.0	37.1	34.2	31.3	28.4	25.5	22.6	19.8	17.0	14.1	11.3	8.5	5.7	2.9	0.2	-2.6	-5.4	-8.1	-10.8	-13.6	-16.3	-19.0	-21.6	**28**
29	57.3	54.4	51.5	48.6	45.7	42.8	40.0	37.1	34.3	31.4	28.6	25.8	23.0	20.2	17.4	14.7	11.9	9.2	6.4	3.7	1.0	-1.7	-4.4	-7.1	-9.8	-12.4	-15.1	-17.7	-20.3	-22.9	-25.5	**29**
30	50.4	47.6	44.7	41.9	39.1	36.3	33.5	30.8	28.0	25.2	22.5	19.8	17.1	14.3	11.6	9.0	6.3	3.6	1.0	-1.7	-4.3	-6.9	-9.5	-12.1	-14.7	-17.3	-19.9	-22.4	-24.9	-27.5	-30.0	**30**
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	

Table 20: Payoff table B for the CN and CNi treatment

TABLE B

The choice of the other participant in my group

My choice	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
0	73.3	68.0	62.7	57.4	52.1	46.9	41.6	36.3	31.1	25.9	20.7	15.5	10.3	5.1	-0.1	-5.2	-10.4	-15.5	-20.7	-25.8	-30.9	-36.0	-41.1	-46.1	-51.2	-56.2	-61.3	-66.3	-71.3	-76.3	-81.3	**0**
1	80.6	75.4	70.2	65.0	59.8	54.6	49.4	44.2	39.1	33.9	28.8	23.7	18.6	13.5	8.4	3.3	-1.8	-6.8	-11.9	-16.9	-21.9	-26.9	-31.9	-36.9	-41.9	-46.9	-51.8	-56.8	-61.7	-66.6	-71.6	**1**
2	87.4	82.2	77.1	71.9	66.8	61.7	56.6	51.5	46.5	41.4	36.4	31.3	26.3	21.3	16.3	11.3	6.3	1.3	-3.6	-8.6	-13.5	-18.5	-23.4	-28.3	-33.2	-38.1	-43.0	-47.8	-52.7	-57.5	-62.3	**2**
3	93.5	88.5	83.4	78.4	73.3	68.3	63.3	58.3	53.3	48.3	43.4	38.4	33.5	28.5	23.6	18.7	13.8	8.9	4.0	-0.8	-5.7	-10.6	-15.4	-20.2	-25.0	-29.8	-34.6	-39.4	-44.2	-48.9	-53.7	**3**
4	99.2	94.2	89.2	84.3	79.3	74.4	69.4	64.5	59.6	54.7	49.8	45.0	40.1	35.2	30.4	25.6	20.7	15.9	11.1	6.4	1.6	-3.2	-7.9	-12.7	-17.4	-22.1	-26.8	-31.5	-36.2	-40.9	-45.6	**4**
5	104.3	99.3	94.5	89.6	84.7	79.9	75.0	70.2	65.3	60.5	55.7	50.9	46.2	41.4	36.6	31.9	27.1	22.4	17.7	13.0	8.3	3.6	-1.1	-5.7	-10.4	-15.0	-19.6	-24.2	-28.8	-33.4	-38.0	**5**
6	108.8	103.9	99.1	94.3	89.6	84.8	80.0	75.3	70.5	65.8	61.1	56.4	51.7	47.0	42.3	37.6	33.0	28.3	23.7	19.1	14.5	9.9	5.3	0.7	-3.9	-8.4	-13.0	-17.5	-22.0	-26.5	-31.0	**6**
7	112.7	108.0	103.3	98.6	93.8	89.2	84.5	79.8	75.1	70.5	65.9	61.2	56.6	52.0	47.4	42.8	38.3	33.7	29.1	24.6	20.1	15.6	11.1	6.6	2.1	-2.4	-6.9	-11.3	-15.7	-20.2	-24.6	**7**
8	116.1	111.5	106.8	102.2	97.6	93.0	88.4	83.8	79.2	74.6	70.1	65.5	61.0	56.5	52.0	47.5	43.0	38.5	34.0	29.6	25.1	20.7	16.3	11.9	7.5	3.1	-1.3	-5.7	-10.0	-14.4	-18.7	**8**
9	119.0	114.4	109.9	105.3	100.8	96.2	91.7	87.2	82.7	78.2	73.8	69.3	64.8	60.4	56.0	51.6	47.2	42.8	38.4	34.0	29.6	25.3	20.9	16.6	12.3	8.0	3.7	-0.6	-4.9	-9.1	-13.4	**9**
10	121.3	116.8	112.3	107.8	103.4	98.9	94.5	90.1	85.7	81.3	76.9	72.5	68.1	63.8	59.4	55.1	50.8	46.5	42.2	37.9	33.6	29.3	25.1	20.8	16.6	12.3	8.1	3.9	-0.3	-4.4	-8.6	**10**
11	123.0	118.6	114.2	109.8	105.5	101.1	96.7	92.4	88.1	83.8	79.4	75.1	70.9	66.6	62.3	58.1	53.8	49.6	45.4	41.2	37.0	32.8	28.6	24.4	20.3	16.1	12.0	7.9	3.8	-0.3	-4.4	**11**
12	124.2	119.9	115.6	111.3	107.0	102.7	98.4	94.2	89.9	85.7	81.5	77.2	73.0	68.8	64.7	60.5	56.3	52.2	48.0	43.9	39.8	35.7	31.6	27.5	23.4	19.4	15.3	11.3	7.3	3.3	-0.8	**12**
13	124.8	120.6	116.4	112.1	107.9	103.7	99.5	95.4	91.2	87.0	82.9	78.8	74.6	70.5	66.4	62.4	58.3	54.2	50.2	46.1	42.1	38.1	34.0	30.0	26.1	22.1	18.1	14.2	10.2	6.3	2.4	**13**
14	124.9	120.7	116.6	112.5	108.3	104.2	100.1	96.0	91.9	87.9	83.8	79.7	75.7	71.7	67.7	63.7	59.7	55.7	51.7	47.7	43.8	39.9	35.9	32.0	28.1	24.2	20.3	16.5	12.6	8.7	4.9	**14**
15	124.4	120.3	116.3	112.2	108.2	104.1	100.1	96.1	92.1	88.1	84.1	80.2	76.2	72.3	68.3	64.4	60.5	56.6	52.7	48.8	45.0	41.1	37.3	33.4	29.6	25.8	22.0	18.2	14.4	10.6	6.9	**15**
16	123.4	119.4	115.4	111.4	107.5	103.5	99.6	95.6	91.7	87.8	83.9	80.0	76.2	72.3	68.4	64.6	60.8	57.0	53.2	49.4	45.6	41.8	38.0	34.3	30.5	26.8	23.1	19.4	15.7	12.0	8.3	**16**
17	121.8	117.9	114.0	110.1	106.2	102.3	98.5	94.6	90.8	87.0	83.1	79.3	75.6	71.8	68.0	64.2	60.5	56.8	53.0	49.3	45.6	41.9	38.2	34.6	30.9	27.3	23.6	20.0	16.4	12.8	9.2	**17**
18	119.6	115.8	112.0	108.2	104.4	100.6	96.8	93.0	89.3	85.5	81.8	78.1	74.4	70.7	67.0	63.3	59.7	56.0	52.4	48.7	45.1	41.5	37.9	34.3	30.7	27.2	23.6	20.1	16.5	13.0	9.5	**18**
19	116.9	113.2	109.4	105.7	102.0	98.3	94.6	90.9	87.2	83.6	79.9	76.3	72.7	69.1	65.4	61.9	58.3	54.7	51.1	47.6	44.1	40.5	37.0	33.5	30.0	26.5	23.1	19.6	16.1	12.7	9.3	**19**
20	113.6	110.0	106.3	102.7	99.0	95.4	91.8	88.2	84.6	81.1	77.5	73.9	70.4	66.9	63.3	59.8	56.3	52.8	49.4	45.9	42.4	39.0	35.6	32.1	28.7	25.3	21.9	18.6	15.2	11.8	8.5	**20**
21	109.8	106.2	102.7	99.1	95.6	92.0	88.5	85.0	81.5	78.0	74.5	71.0	67.6	64.1	60.7	57.2	53.8	50.4	47.0	43.6	40.3	36.9	33.6	30.2	26.9	23.6	20.3	17.0	13.7	10.4	7.1	**21**
22	105.4	101.9	98.5	95.0	91.5	88.1	84.6	81.2	77.8	74.3	70.9	67.6	64.2	60.8	57.4	54.1	50.8	47.4	44.1	40.8	37.5	34.3	31.0	27.7	24.5	21.3	18.0	14.8	11.6	8.4	5.2	**22**
23	100.5	97.1	93.7	90.3	86.9	83.5	80.2	76.8	73.5	70.1	66.8	63.5	60.2	56.9	53.7	50.4	47.2	43.9	40.7	37.5	34.3	31.1	27.9	24.7	21.5	18.4	15.2	12.1	9.0	5.9	2.8	**23**
24	95.0	91.7	88.4	85.0	81.7	78.5	75.2	71.9	68.6	65.4	62.2	58.9	55.7	52.5	49.3	46.2	43.0	39.8	36.7	33.5	30.4	27.3	24.2	21.1	18.0	15.0	11.9	8.8	5.8	2.8	-0.2	**24**
25	89.0	85.7	82.5	79.2	76.0	72.8	69.6	66.4	63.3	60.1	56.9	53.8	50.7	47.6	44.4	41.3	38.3	35.2	32.1	29.1	26.0	23.0	20.0	17.0	14.0	11.0	8.0	5.0	2.1	-0.9	-3.8	**25**
26	82.4	79.2	76.0	72.9	69.8	66.6	63.5	60.4	57.3	54.2	51.2	48.1	45.1	42.0	39.0	36.0	33.0	30.0	27.0	24.0	21.1	18.1	15.2	12.3	9.3	6.4	3.5	0.7	-2.2	-5.1	-7.9	**26**
27	75.2	72.1	69.0	66.0	62.9	59.9	56.9	53.8	50.8	47.8	44.8	41.9	38.9	35.9	33.0	30.1	27.1	24.2	21.3	18.4	15.6	12.7	9.8	7.0	4.2	1.3	-1.5	-4.3	-7.1	-9.8	-12.6	**27**
28	67.5	64.5	61.5	58.5	55.5	52.6	49.6	46.7	43.8	40.9	37.9	35.1	32.2	29.3	26.4	23.6	20.7	17.9	15.1	12.3	9.5	6.7	3.9	1.2	-1.6	-4.3	-7.0	-9.8	-12.5	-15.2	-17.9	**28**
29	59.2	56.3	53.4	50.5	47.6	44.7	41.9	39.0	36.2	33.3	30.5	27.7	24.9	22.1	19.3	16.6	13.8	11.0	8.3	5.6	2.9	0.2	-2.5	-5.2	-7.9	-10.5	-13.2	-15.8	-18.4	-21.0	-23.6	**29**
30	50.4	47.6	44.7	41.9	39.1	36.3	33.5	30.8	28.0	25.2	22.5	19.8	17.1	14.3	11.6	9.0	6.3	3.6	1.0	-1.7	-4.3	-6.9	-9.5	-12.1	-14.7	-17.3	-19.9	-22.4	-24.9	-27.5	-30.0	**30**
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	

TABLE A

The choice of the other participant in my group

My choice	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	
0	-30.0	-27.5	-24.9	-22.4	-19.9	-17.3	-14.7	-12.1	-9.5	-6.9	-4.3	-1.7	1.0	3.6	6.3	9.0	11.6	14.3	17.1	19.8	22.5	25.2	28.0	30.8	33.5	36.3	39.1	41.9	44.7	47.6	50.4	**0**
1	-23.9	-21.5	-19.0	-16.5	-14.1	-11.6	-9.1	-6.6	-4.1	-1.6	1.0	3.5	6.1	8.7	11.2	13.8	16.4	19.0	21.7	24.3	27.0	29.6	32.3	35.0	37.7	40.4	43.1	45.8	48.5	51.3	54.0	**1**
2	-18.3	-16.0	-13.6	-11.2	-8.9	-6.5	-4.0	-1.6	0.8	3.3	5.7	8.2	10.7	13.1	15.6	18.1	20.7	23.2	25.7	28.3	30.9	33.4	36.0	38.6	41.2	43.8	46.5	49.1	51.8	54.4	57.1	**2**
3	-13.3	-11.1	-8.8	-6.5	-4.2	-1.9	0.5	2.8	5.1	7.5	9.9	12.3	14.7	17.1	19.5	21.9	24.3	26.8	29.3	31.7	34.2	36.7	39.2	41.7	44.2	46.8	49.3	51.9	54.5	57.0	59.6	**3**
4	-8.9	-6.7	-4.5	-2.3	-0.1	2.2	4.4	6.7	8.9	11.2	13.5	15.8	18.1	20.4	22.8	25.1	27.5	29.8	32.2	34.6	37.0	39.4	41.8	44.3	46.7	49.2	51.6	54.1	56.6	59.1	61.6	**4**
5	-5.0	-2.9	-0.8	1.3	3.5	5.6	7.8	10.0	12.1	14.3	16.6	18.8	21.0	23.2	25.5	27.8	30.0	32.3	34.6	36.9	39.2	41.6	43.9	46.2	48.6	51.0	53.4	55.8	58.2	60.6	63.0	**5**
6	-1.7	0.3	2.4	4.4	6.5	8.5	10.6	12.7	14.8	16.9	19.1	21.2	23.3	25.5	27.7	29.8	32.0	34.2	36.4	38.7	40.9	43.1	45.4	47.7	50.0	52.2	54.5	56.9	59.2	61.5	63.9	**6**
7	1.1	3.0	5.0	6.9	8.9	10.9	12.9	14.9	16.9	19.0	21.0	23.1	25.1	27.2	29.3	31.4	33.5	35.6	37.7	39.9	42.0	44.2	46.4	48.5	50.7	52.9	55.2	57.4	59.6	61.9	64.1	**7**
8	3.3	5.1	7.0	8.9	10.8	12.7	14.6	16.5	18.5	20.4	22.4	24.4	26.3	28.3	30.3	32.4	34.4	36.4	38.5	40.5	42.6	44.7	46.8	48.9	51.0	53.1	55.2	57.4	59.5	61.7	63.9	**8**
9	4.9	6.7	8.5	10.3	12.1	13.9	15.8	17.6	19.5	21.3	23.2	25.1	27.0	28.9	30.8	32.8	34.7	36.7	38.6	40.6	42.6	44.6	46.6	48.6	50.7	52.7	54.8	56.8	58.9	61.0	63.1	**9**
10	6.0	7.7	9.5	11.2	12.9	14.6	16.4	18.1	19.9	21.7	23.5	25.3	27.1	28.9	30.8	32.6	34.5	36.4	38.3	40.1	42.1	44.0	45.9	47.8	49.8	51.7	53.7	55.7	57.7	59.7	61.7	**10**
11	6.6	8.2	9.8	11.5	13.1	14.8	16.4	18.1	19.8	21.5	23.2	24.9	26.7	28.4	30.2	31.9	33.7	35.5	37.3	39.1	40.9	42.8	44.6	46.5	48.3	50.2	52.1	54.0	55.9	57.8	59.8	**11**
12	6.6	8.1	9.7	11.2	12.8	14.4	15.9	17.5	19.1	20.8	22.4	24.0	25.7	27.3	29.0	30.7	32.4	34.1	35.8	37.5	39.3	41.0	42.8	44.6	46.4	48.2	50.0	51.8	53.6	55.4	57.3	**12**
13	6.0	7.5	8.9	10.4	11.9	13.4	14.9	16.4	17.9	19.5	21.0	22.6	24.1	25.7	27.3	28.9	30.5	32.1	33.8	35.4	37.1	38.7	40.4	42.1	43.8	45.5	47.2	49.0	50.7	52.5	54.2	**13**
14	4.9	6.3	7.6	9.0	10.4	11.8	13.3	14.7	16.1	17.6	19.1	20.5	22.0	23.5	25.0	26.5	28.1	29.6	31.2	32.7	34.3	35.9	37.5	39.1	40.7	42.3	44.0	45.6	47.3	49.0	50.7	**14**
15	3.2	4.5	5.8	7.1	8.4	9.7	11.1	12.4	13.8	15.2	16.6	17.9	19.3	20.8	22.2	23.6	25.1	26.5	28.0	29.5	31.0	32.5	34.0	35.5	37.1	38.6	40.2	41.7	43.3	44.9	46.5	**15**
16	1.0	2.2	3.4	4.6	5.9	7.1	8.4	9.6	10.9	12.2	13.5	14.8	16.1	17.5	18.8	20.2	21.5	22.9	24.3	25.7	27.1	28.5	29.9	31.4	32.8	34.3	35.8	37.3	38.8	40.3	41.8	**16**
17	-1.8	-0.7	0.4	1.6	2.7	3.9	5.1	6.3	7.5	8.7	9.9	11.1	12.3	13.6	14.9	16.1	17.4	18.7	20.0	21.3	22.7	24.0	25.3	26.7	28.1	29.5	30.8	32.3	33.7	35.1	36.5	**17**
18	-5.1	-4.1	-3.1	-2.0	-0.9	0.1	1.2	2.3	3.4	4.6	5.7	6.9	8.0	9.2	10.4	11.5	12.7	14.0	15.2	16.4	17.7	18.9	20.2	21.5	22.7	24.0	25.4	26.7	28.0	29.4	30.7	**18**
19	-9.0	-8.1	-7.1	-6.2	-5.2	-4.2	-3.2	-2.1	-1.1	-0.1	1.0	2.0	3.1	4.2	5.3	6.4	7.5	8.7	9.8	10.9	12.1	13.3	14.5	15.7	16.9	18.1	19.3	20.5	21.8	23.1	24.3	**19**
20	-13.5	-12.6	-11.7	-10.9	-10.0	-9.0	-8.1	-7.2	-6.2	-5.3	-4.3	-3.3	-2.3	-1.3	-0.3	0.7	1.7	2.8	3.9	4.9	6.0	7.1	8.2	9.3	10.4	11.6	12.7	13.9	15.0	16.2	17.4	**20**
21	-18.5	-17.7	-16.9	-16.1	-15.3	-14.5	-13.6	-12.8	-11.9	-11.0	-10.1	-9.2	-8.3	-7.4	-6.5	-5.5	-4.6	-3.6	-2.6	-1.7	-0.7	0.3	1.4	2.4	3.4	4.5	5.6	6.6	7.7	8.8	9.9	**21**
22	-24.1	-23.4	-22.7	-21.9	-21.2	-20.4	-19.7	-18.9	-18.1	-17.3	-16.5	-15.7	-14.9	-14.1	-13.2	-12.3	-11.5	-10.6	-9.7	-8.8	-7.9	-7.0	-6.0	-5.1	-4.1	-3.1	-2.2	-1.2	-0.2	0.8	1.9	**22**
23	-30.2	-29.6	-29.0	-28.3	-27.6	-27.0	-26.3	-25.6	-24.9	-24.2	-23.5	-22.7	-22.0	-21.3	-20.5	-19.7	-18.9	-18.1	-17.3	-16.5	-15.7	-14.8	-14.0	-13.1	-12.2	-11.3	-10.4	-9.5	-8.6	-7.7	-6.7	**23**
24	-36.9	-36.3	-35.8	-35.2	-34.7	-34.1	-33.5	-32.9	-32.3	-31.6	-31.0	-30.3	-29.7	-29.0	-28.3	-27.6	-26.9	-26.2	-25.5	-24.7	-24.0	-23.2	-22.5	-21.7	-20.9	-20.1	-19.3	-18.4	-17.6	-16.7	-15.9	**24**
25	-44.1	-43.7	-43.2	-42.7	-42.2	-41.7	-41.2	-40.7	-40.2	-39.6	-39.1	-38.5	-37.9	-37.3	-36.7	-36.1	-35.5	-34.8	-34.2	-33.5	-32.9	-32.2	-31.5	-30.8	-30.1	-29.4	-28.6	-27.9	-27.1	-26.4	-25.6	**25**
26	-51.9	-51.5	-51.2	-50.8	-50.4	-49.9	-49.5	-49.1	-48.6	-48.1	-47.7	-47.2	-46.7	-46.2	-45.7	-45.1	-44.6	-44.0	-43.5	-42.9	-42.3	-41.7	-41.1	-40.5	-39.9	-39.2	-38.6	-37.9	-37.2	-36.6	-35.9	**26**
27	-60.3	-60.0	-59.7	-59.4	-59.0	-58.7	-58.3	-58.0	-57.6	-57.2	-56.8	-56.4	-56.0	-55.6	-55.2	-54.7	-54.3	-53.8	-53.3	-52.8	-52.3	-51.8	-51.3	-50.7	-50.2	-49.6	-49.1	-48.5	-47.9	-47.3	-46.7	**27**
28	-69.2	-69.0	-68.7	-68.5	-68.3	-68.0	-67.7	-67.5	-67.2	-66.9	-66.6	-66.3	-65.9	-65.6	-65.2	-64.9	-64.5	-64.1	-63.7	-63.3	-62.9	-62.4	-62.0	-61.5	-61.1	-60.6	-60.1	-59.6	-59.1	-58.6	-58.1	**28**
29	-78.6	-78.5	-78.4	-78.2	-78.1	-77.9	-77.7	-77.5	-77.3	-77.1	-76.9	-76.6	-76.4	-76.1	-75.8	-75.6	-75.3	-75.0	-74.6	-74.3	-74.0	-73.6	-73.3	-72.9	-72.5	-72.1	-71.7	-71.3	-70.9	-70.5	-70.0	**29**
30	-88.7	-88.6	-88.5	-88.5	-88.4	-88.3	-88.2	-88.1	-88.0	-87.8	-87.7	-87.5	-87.4	-87.2	-87.0	-86.8	-86.6	-86.4	-86.1	-85.9	-85.7	-85.4	-85.1	-84.8	-84.5	-84.2	-83.9	-83.6	-83.2	-82.9	-82.5	**30**
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	

Table 21: Payoff table A for the SP and SPi treatment

Table 22: Payoff table B for the SP and SPi treatment

TABLE B

The choice of the other participant in my group

My choice	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	
0	-30.0	-27.5	-24.9	-22.4	-19.9	-17.3	-14.7	-12.1	-9.5	-6.9	-4.3	-1.7	1.0	3.6	6.3	9.0	11.6	14.3	17.1	19.8	22.5	25.2	28.0	30.8	33.5	36.3	39.1	41.9	44.7	47.6	50.4	**0**
1	-21.7	-19.3	-16.8	-14.4	-11.9	-9.4	-6.9	-4.4	-1.9	0.6	3.2	5.7	8.3	10.8	13.4	16.0	18.6	21.2	23.8	26.5	29.1	31.8	34.5	37.1	39.8	42.5	45.2	48.0	50.7	53.4	56.2	**1**
2	-14.0	-11.6	-9.3	-6.9	-4.5	-2.1	0.3	2.7	5.1	7.6	10.0	12.5	15.0	17.5	20.0	22.5	25.0	27.5	30.1	32.6	35.2	37.8	40.4	43.0	45.6	48.2	50.8	53.5	56.1	58.8	61.4	**2**
3	-6.8	-4.6	-2.3	0.0	2.3	4.6	7.0	9.3	11.7	14.0	16.4	18.8	21.2	23.6	26.0	28.4	30.9	33.3	35.8	38.2	40.7	43.2	45.7	48.2	50.8	53.3	55.8	58.4	61.0	63.5	66.1	**3**
4	-0.2	2.0	4.2	6.4	8.6	10.8	13.1	15.3	17.6	19.9	22.2	24.5	26.8	29.1	31.4	33.8	36.1	38.5	40.9	43.3	45.7	48.1	50.5	52.9	55.4	57.8	60.3	62.8	65.3	67.8	70.3	**4**
5	5.8	7.9	10.1	12.2	14.3	16.5	18.6	20.8	23.0	25.2	27.4	29.6	31.8	34.1	36.3	38.6	40.9	43.2	45.5	47.8	50.1	52.4	54.7	57.1	59.5	61.8	64.2	66.6	69.0	71.4	73.8	**5**
6	11.3	13.3	15.4	17.4	19.5	21.6	23.6	25.7	27.8	29.9	32.1	34.2	36.4	38.5	40.7	42.9	45.0	47.3	49.5	51.7	53.9	56.2	58.4	60.7	63.0	65.3	67.6	69.9	72.2	74.5	76.9	**6**
7	16.3	18.2	20.2	22.1	24.1	26.1	28.1	30.1	32.1	34.1	36.2	38.2	40.3	42.4	44.5	46.6	48.7	50.8	52.9	55.1	57.2	59.4	61.5	63.7	65.9	68.1	70.4	72.6	74.8	77.1	79.3	**7**
8	20.6	22.5	24.4	26.3	28.2	30.1	32.0	33.9	35.8	37.8	39.7	41.7	43.7	45.7	47.7	49.7	51.7	53.8	55.8	57.9	59.9	62.0	64.1	66.2	68.3	70.5	72.6	74.7	76.9	79.1	81.2	**8**
9	24.5	26.3	28.0	29.8	31.7	33.5	35.3	37.2	39.0	40.9	42.8	44.6	46.5	48.4	50.4	52.3	54.2	56.2	58.2	60.1	62.1	64.1	66.1	68.2	70.2	72.2	74.3	76.3	78.4	80.5	82.6	**9**
10	27.7	29.4	31.2	32.9	34.6	36.3	38.1	39.8	41.6	43.4	45.2	47.0	48.8	50.6	52.5	54.3	56.2	58.1	60.0	61.8	63.7	65.7	67.6	69.5	71.5	73.4	75.4	77.4	79.4	81.4	83.4	**10**
11	30.5	32.1	33.7	35.3	37.0	38.6	40.3	42.0	43.7	45.4	47.1	48.8	50.5	52.3	54.0	55.8	57.6	59.4	61.2	63.0	64.8	66.6	68.5	70.3	72.2	74.1	76.0	77.9	79.8	81.7	83.6	**11**
12	32.6	34.2	35.7	37.3	38.8	40.4	42.0	43.6	45.2	46.8	48.4	50.1	51.7	53.4	55.1	56.7	58.4	60.1	61.9	63.6	65.3	67.1	68.8	70.6	72.4	74.2	76.0	77.8	79.6	81.5	83.3	**12**
13	34.2	35.7	37.1	38.6	40.1	41.6	43.1	44.6	46.1	47.7	49.2	50.8	52.3	53.9	55.5	57.1	58.7	60.3	62.0	63.6	65.3	66.9	68.6	70.3	72.0	73.7	75.5	77.2	78.9	80.7	82.5	**13**
14	35.3	36.6	38.0	39.4	40.8	42.2	43.6	45.1	46.5	48.0	49.4	50.9	52.4	53.9	55.4	56.9	58.4	60.0	61.5	63.1	64.7	66.3	67.9	69.5	71.1	72.7	74.4	76.0	77.7	79.3	81.0	**14**
15	35.8	37.1	38.4	39.7	41.0	42.3	43.6	45.0	46.3	47.7	49.1	50.5	51.9	53.3	54.7	56.2	57.6	59.1	60.6	62.0	63.5	65.0	66.5	68.1	69.6	71.1	72.7	74.3	75.9	77.4	79.0	**15**
16	35.7	36.9	38.1	39.3	40.6	41.8	43.1	44.3	45.6	46.9	48.2	49.5	50.8	52.2	53.5	54.9	56.2	57.6	59.0	60.4	61.8	63.2	64.7	66.1	67.6	69.0	70.5	72.0	73.5	75.0	76.5	**16**
17	35.1	36.2	37.3	38.5	39.6	40.8	42.0	43.1	44.3	45.5	46.8	48.0	49.2	50.5	51.7	53.0	54.3	55.6	56.9	58.2	59.5	60.9	62.2	63.6	65.0	66.3	67.7	69.1	70.6	72.0	73.4	**17**
18	33.9	35.0	36.0	37.1	38.1	39.2	40.3	41.4	42.5	43.6	44.8	45.9	47.1	48.2	49.4	50.6	51.8	53.0	54.2	55.5	56.7	58.0	59.2	60.5	61.8	63.1	64.4	65.7	67.1	68.4	69.8	**18**
19	32.2	33.1	34.1	35.1	36.1	37.1	38.1	39.1	40.1	41.2	42.2	43.3	44.3	45.4	46.5	47.6	48.8	49.9	51.0	52.2	53.3	54.5	55.7	56.9	58.1	59.3	60.5	61.8	63.0	64.3	65.6	**19**
20	29.9	30.8	31.7	32.5	33.4	34.4	35.3	36.2	37.2	38.1	39.1	40.1	41.1	42.1	43.1	44.1	45.1	46.2	47.3	48.3	49.4	50.5	51.6	52.7	53.8	55.0	56.1	57.3	58.4	59.6	60.8	**20**
21	27.1	27.8	28.6	29.5	30.3	31.1	31.9	32.8	33.7	34.5	35.4	36.3	37.2	38.2	39.1	40.0	41.0	41.9	42.9	43.9	44.9	45.9	46.9	48.0	49.0	50.1	51.1	52.2	53.3	54.4	55.5	**21**
22	23.7	24.4	25.1	25.8	26.5	27.3	28.1	28.8	29.6	30.4	31.2	32.0	32.8	33.7	34.5	35.4	36.3	37.1	38.0	38.9	39.9	40.8	41.7	42.7	43.6	44.6	45.6	46.6	47.6	48.6	49.6	**22**
23	19.7	20.3	21.0	21.6	22.3	22.9	23.6	24.3	25.0	25.7	26.4	27.2	27.9	28.7	29.4	30.2	31.0	31.8	32.6	33.4	34.3	35.1	35.9	36.8	37.7	38.6	39.5	40.4	41.3	42.2	43.2	**23**
24	15.2	15.7	16.3	16.8	17.4	18.0	18.6	19.2	19.8	20.5	21.1	21.7	22.4	23.1	23.8	24.5	25.2	25.9	26.6	27.3	28.1	28.9	29.6	30.4	31.2	32.0	32.8	33.6	34.5	35.3	36.2	**24**
25	10.1	10.6	11.0	11.5	12.0	12.5	13.0	13.6	14.1	14.6	15.2	15.8	16.3	16.9	17.5	18.1	18.8	19.4	20.0	20.7	21.4	22.1	22.7	23.4	24.2	24.9	25.6	26.3	27.1	27.9	28.6	**25**
26	4.5	4.9	5.3	5.7	6.1	6.5	6.9	7.4	7.8	8.3	8.7	9.2	9.7	10.2	10.8	11.3	11.8	12.4	12.9	13.5	14.1	14.7	15.3	15.9	16.5	17.2	17.8	18.5	19.2	19.9	20.5	**26**
27	-1.7	-1.4	-1.1	-0.8	-0.4	-0.1	0.2	0.6	1.0	1.4	1.7	2.1	2.6	3.0	3.4	3.9	4.3	4.8	5.3	5.8	6.3	6.8	7.3	7.8	8.4	8.9	9.5	10.1	10.7	11.3	11.9	**27**
28	-8.4	-8.2	-8.0	-7.8	-7.5	-7.3	-7.0	-6.7	-6.4	-6.1	-5.8	-5.5	-5.2	-4.8	-4.5	-4.1	-3.7	-3.3	-2.9	-2.5	-2.1	-1.7	-1.2	-0.8	-0.3	0.1	0.6	1.1	1.6	2.2	2.7	**28**
29	-15.7	-15.6	-15.4	-15.3	-15.1	-15.0	-14.8	-14.6	-14.4	-14.2	-13.9	-13.7	-13.4	-13.2	-12.9	-12.6	-12.3	-12.0	-11.7	-11.4	-11.1	-10.7	-10.3	-10.0	-9.6	-9.2	-8.8	-8.4	-8.0	-7.5	-7.1	**29**
30	-23.6	-23.5	-23.5	-23.4	-23.3	-23.2	-23.1	-23.0	-22.9	-22.7	-22.6	-22.4	-22.3	-22.1	-21.9	-21.7	-21.5	-21.3	-21.1	-20.8	-20.6	-20.3	-20.0	-19.7	-19.4	-19.1	-18.8	-18.5	-18.1	-17.8	-17.4	**30**
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	

Table 23: Payoff table A for the SN and SNi treatment

TABLE A

The choice of the other participant in my group

My choice	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
0	-82.5	-82.9	-83.2	-83.6	-83.9	-84.2	-84.5	-84.8	-85.1	-85.4	-85.7	-85.9	-86.1	-86.4	-86.6	-86.8	-87.0	-87.2	-87.4	-87.5	-87.7	-87.8	-88.0	-88.1	-88.2	-88.3	-88.4	-88.5	-88.5	-88.6	-88.7	**0**
1	-70.0	-70.5	-70.9	-71.3	-71.7	-72.1	-72.5	-72.9	-73.3	-73.6	-74.0	-74.3	-74.6	-75.0	-75.3	-75.6	-75.8	-76.1	-76.4	-76.6	-76.9	-77.1	-77.3	-77.5	-77.7	-77.9	-78.1	-78.2	-78.4	-78.5	-78.6	**1**
2	-58.1	-58.6	-59.1	-59.6	-60.1	-60.6	-61.1	-61.5	-62.0	-62.4	-62.9	-63.3	-63.7	-64.1	-64.5	-64.9	-65.2	-65.6	-65.9	-66.3	-66.6	-66.9	-67.2	-67.5	-67.7	-68.0	-68.3	-68.5	-68.7	-69.0	-69.2	**2**
3	-46.7	-47.3	-47.9	-48.5	-49.1	-49.6	-50.2	-50.7	-51.3	-51.8	-52.3	-52.8	-53.3	-53.8	-54.3	-54.7	-55.2	-55.6	-56.0	-56.4	-56.8	-57.2	-57.6	-58.0	-58.3	-58.7	-59.0	-59.4	-59.7	-60.0	-60.3	**3**
4	-35.9	-36.6	-37.2	-37.9	-38.6	-39.2	-39.9	-40.5	-41.1	-41.7	-42.3	-42.9	-43.5	-44.0	-44.6	-45.1	-45.7	-46.2	-46.7	-47.2	-47.7	-48.1	-48.6	-49.1	-49.5	-49.9	-50.4	-50.8	-51.2	-51.5	-51.9	**4**
5	-25.6	-26.4	-27.1	-27.9	-28.6	-29.4	-30.1	-30.8	-31.5	-32.2	-32.9	-33.5	-34.2	-34.8	-35.5	-36.1	-36.7	-37.3	-37.9	-38.5	-39.1	-39.6	-40.2	-40.7	-41.2	-41.7	-42.2	-42.7	-43.2	-43.7	-44.1	**5**
6	-15.9	-16.7	-17.6	-18.4	-19.3	-20.1	-20.9	-21.7	-22.5	-23.2	-24.0	-24.7	-25.5	-26.2	-26.9	-27.6	-28.3	-29.0	-29.7	-30.3	-31.0	-31.6	-32.3	-32.9	-33.5	-34.1	-34.7	-35.2	-35.8	-36.3	-36.9	**6**
7	-6.7	-7.7	-8.6	-9.5	-10.4	-11.3	-12.2	-13.1	-14.0	-14.8	-15.7	-16.5	-17.3	-18.1	-18.9	-19.7	-20.5	-21.3	-22.0	-22.7	-23.5	-24.2	-24.9	-25.6	-26.3	-27.0	-27.6	-28.3	-29.0	-29.6	-30.2	**7**
8	1.9	0.8	-0.2	-1.2	-2.2	-3.1	-4.1	-5.1	-6.0	-7.0	-7.9	-8.8	-9.7	-10.6	-11.5	-12.3	-13.2	-14.1	-14.9	-15.7	-16.5	-17.3	-18.1	-18.9	-19.7	-20.4	-21.2	-21.9	-22.7	-23.4	-24.1	**8**
9	9.9	8.8	7.7	6.6	5.6	4.5	3.4	2.4	1.4	0.3	-0.7	-1.7	-2.6	-3.6	-4.6	-5.5	-6.5	-7.4	-8.3	-9.2	-10.1	-11.0	-11.9	-12.8	-13.6	-14.5	-15.3	-16.1	-16.9	-17.7	-18.5	**9**
10	17.4	16.2	15.0	13.9	12.7	11.6	10.4	9.3	8.2	7.1	6.0	4.9	3.9	2.8	1.7	0.7	-0.3	-1.3	-2.3	-3.3	-4.3	-5.3	-6.2	-7.2	-8.1	-9.0	-10.0	-10.9	-11.7	-12.6	-13.5	**10**
11	24.3	23.1	21.8	20.5	19.3	18.1	16.9	15.7	14.5	13.3	12.1	10.9	9.8	8.7	7.5	6.4	5.3	4.2	3.1	2.0	1.0	-0.1	-1.1	-2.1	-3.2	-4.2	-5.2	-6.2	-7.1	-8.1	-9.0	**11**
12	30.7	29.4	28.0	26.7	25.4	24.0	22.7	21.5	20.2	18.9	17.7	16.4	15.2	14.0	12.7	11.5	10.4	9.2	8.0	6.9	5.7	4.6	3.4	2.3	1.2	0.1	-0.9	-2.0	-3.1	-4.1	-5.1	**12**
13	36.5	35.1	33.7	32.3	30.8	29.5	28.1	26.7	25.3	24.0	22.7	21.3	20.0	18.7	17.4	16.1	14.9	13.6	12.3	11.1	9.9	8.7	7.5	6.3	5.1	3.9	2.7	1.6	0.4	-0.7	-1.8	**13**
14	41.8	40.3	38.8	37.3	35.8	34.3	32.8	31.4	29.9	28.5	27.1	25.7	24.3	22.9	21.5	20.2	18.8	17.5	16.1	14.8	13.5	12.2	10.9	9.6	8.4	7.1	5.9	4.6	3.4	2.2	1.0	**14**
15	46.5	44.9	43.3	41.7	40.2	38.6	37.1	35.5	34.0	32.5	31.0	29.5	28.0	26.5	25.1	23.6	22.2	20.8	19.3	17.9	16.6	15.2	13.8	12.4	11.1	9.7	8.4	7.1	5.8	4.5	3.2	**15**
16	50.7	49.0	47.3	45.6	44.0	42.3	40.7	39.1	37.5	35.9	34.3	32.7	31.2	29.6	28.1	26.5	25.0	23.5	22.0	20.5	19.1	17.6	16.1	14.7	13.3	11.8	10.4	9.0	7.6	6.3	4.9	**16**
17	54.2	52.5	50.7	49.0	47.2	45.5	43.8	42.1	40.4	38.7	37.1	35.4	33.8	32.1	30.5	28.9	27.3	25.7	24.1	22.6	21.0	19.5	17.9	16.4	14.9	13.4	11.9	10.4	8.9	7.5	6.0	**17**
18	57.3	55.4	53.6	51.8	50.0	48.2	46.4	44.6	42.8	41.0	39.3	37.5	35.8	34.1	32.4	30.7	29.0	27.3	25.7	24.0	22.4	20.8	19.1	17.5	15.9	14.4	12.8	11.2	9.7	8.1	6.6	**18**
19	59.8	57.8	55.9	54.0	52.1	50.2	48.3	46.5	44.6	42.8	40.9	39.1	37.3	35.5	33.7	31.9	30.2	28.4	26.7	24.9	23.2	21.5	19.8	18.1	16.4	14.8	13.1	11.5	9.8	8.2	6.6	**19**
20	61.7	59.7	57.7	55.7	53.7	51.7	49.8	47.8	45.9	44.0	42.1	40.1	38.3	36.4	34.5	32.6	30.8	28.9	27.1	25.3	23.5	21.7	19.9	18.1	16.4	14.6	12.9	11.2	9.5	7.7	6.0	**20**
21	63.1	61.0	58.9	56.8	54.8	52.7	50.7	48.6	46.6	44.6	42.6	40.6	38.6	36.7	34.7	32.8	30.8	28.9	27.0	25.1	23.2	21.3	19.5	17.6	15.8	13.9	12.1	10.3	8.5	6.7	4.9	**21**
22	63.9	61.7	59.5	57.4	55.2	53.1	51.0	48.9	46.8	44.7	42.6	40.5	38.5	36.4	34.4	32.4	30.3	28.3	26.3	24.4	22.4	20.4	18.5	16.5	14.6	12.7	10.8	8.9	7.0	5.1	3.3	**22**
23	64.1	61.9	59.6	57.4	55.2	52.9	50.7	48.5	46.4	44.2	42.0	39.9	37.7	35.6	33.5	31.4	29.3	27.2	25.1	23.1	21.0	19.0	16.9	14.9	12.9	10.9	8.9	6.9	5.0	3.0	1.1	**23**
24	63.9	61.5	59.2	56.9	54.5	52.2	50.0	47.7	45.4	43.1	40.9	38.7	36.4	34.2	32.0	29.8	27.7	25.5	23.3	21.2	19.1	16.9	14.8	12.7	10.6	8.5	6.5	4.4	2.4	0.3	-1.7	**24**
25	63.0	60.6	58.2	55.8	53.4	51.0	48.6	46.2	43.9	41.6	39.2	36.9	34.6	32.3	30.0	27.8	25.5	23.2	21.0	18.8	16.6	14.3	12.1	10.0	7.8	5.6	3.5	1.3	-0.8	-2.9	-5.0	**25**
26	61.6	59.1	56.6	54.1	51.6	49.2	46.7	44.3	41.8	39.4	37.0	34.6	32.2	29.8	27.5	25.1	22.8	20.4	18.1	15.8	13.5	11.2	8.9	6.7	4.4	2.2	-0.1	-2.3	-4.5	-6.7	-8.9	**26**
27	59.6	57.0	54.5	51.9	49.3	46.8	44.2	41.7	39.2	36.7	34.2	31.7	29.3	26.8	24.3	21.9	19.5	17.1	14.7	12.3	9.9	7.5	5.1	2.8	0.5	-1.9	-4.2	-6.5	-8.8	-11.1	-13.3	**27**
28	57.1	54.4	51.8	49.1	46.5	43.8	41.2	38.6	36.0	33.4	30.9	28.3	25.7	23.2	20.7	18.1	15.6	13.1	10.7	8.2	5.7	3.3	0.8	-1.6	-4.0	-6.5	-8.9	-11.2	-13.6	-16.0	-18.3	**28**
29	54.0	51.3	48.5	45.8	43.1	40.4	37.7	35.0	32.3	29.6	27.0	24.3	21.7	19.0	16.4	13.8	11.2	8.7	6.1	3.5	1.0	-1.6	-4.1	-6.6	-9.1	-11.6	-14.1	-16.5	-19.0	-21.5	-23.9	**29**
30	50.4	47.6	44.7	41.9	39.1	36.3	33.5	30.8	28.0	25.2	22.5	19.8	17.1	14.3	11.6	9.0	6.3	3.6	1.0	-1.7	-4.3	-6.9	-9.5	-12.1	-14.7	-17.3	-19.9	-22.4	-24.9	-27.5	-30.0	**30**
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	

Table 24: Payoff table B for the SN and SNi treatment

TABLE B

	The choice of the other participant in my group																															
My choice	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	
0	-17.4	-17.8	-18.1	-18.5	-18.8	-19.1	-19.4	-19.7	-20.0	-20.3	-20.6	-20.8	-21.1	-21.3	-21.5	-21.7	-21.9	-22.1	-22.3	-22.4	-22.6	-22.7	-22.9	-23.0	-23.1	-23.2	-23.3	-23.4	-23.5	-23.5	-23.6	**0**
1	-7.1	-7.5	-8.0	-8.4	-8.8	-9.2	-9.6	-10.0	-10.3	-10.7	-11.1	-11.4	-11.7	-12.0	-12.3	-12.6	-12.9	-13.2	-13.4	-13.7	-13.9	-14.2	-14.4	-14.6	-14.8	-15.0	-15.1	-15.3	-15.4	-15.6	-15.7	**1**
2	2.7	2.2	1.6	1.1	0.6	0.1	-0.3	-0.8	-1.2	-1.7	-2.1	-2.5	-2.9	-3.3	-3.7	-4.1	-4.5	-4.8	-5.2	-5.5	-5.8	-6.1	-6.4	-6.7	-7.0	-7.3	-7.5	-7.8	-8.0	-8.2	-8.4	**2**
3	11.9	11.3	10.7	10.1	9.5	8.9	8.4	7.8	7.3	6.8	6.3	5.8	5.3	4.8	4.3	3.9	3.4	3.0	2.6	2.1	1.7	1.4	1.0	0.6	0.2	-0.1	-0.4	-0.8	-1.1	-1.4	-1.7	**3**
4	20.5	19.9	19.2	18.5	17.8	17.2	16.5	15.9	15.3	14.7	14.1	13.5	12.9	12.4	11.8	11.3	10.8	10.2	9.7	9.2	8.7	8.3	7.8	7.4	6.9	6.5	6.1	5.7	5.3	4.9	4.5	**4**
5	28.6	27.9	27.1	26.3	25.6	24.9	24.2	23.4	22.7	22.1	21.4	20.7	20.0	19.4	18.8	18.1	17.5	16.9	16.3	15.8	15.2	14.6	14.1	13.6	13.0	12.5	12.0	11.5	11.0	10.6	10.1	**5**
6	36.2	35.3	34.5	33.6	32.8	32.0	31.2	30.4	29.6	28.9	28.1	27.3	26.6	25.9	25.2	24.5	23.8	23.1	22.4	21.7	21.1	20.5	19.8	19.2	18.6	18.0	17.4	16.8	16.3	15.7	15.2	**6**
7	43.2	42.2	41.3	40.4	39.5	38.6	37.7	36.8	35.9	35.1	34.3	33.4	32.6	31.8	31.0	30.2	29.4	28.7	27.9	27.2	26.4	25.7	25.0	24.3	23.6	22.9	22.3	21.6	21.0	20.3	19.7	**7**
8	49.6	48.6	47.6	46.6	45.6	44.6	43.6	42.7	41.7	40.8	39.9	38.9	38.0	37.1	36.3	35.4	34.5	33.7	32.8	32.0	31.2	30.4	29.6	28.8	28.1	27.3	26.5	25.8	25.1	24.4	23.7	**8**
9	55.5	54.4	53.3	52.2	51.1	50.1	49.0	48.0	46.9	45.9	44.9	43.9	42.9	41.9	41.0	40.0	39.1	38.2	37.2	36.3	35.4	34.5	33.7	32.8	31.9	31.1	30.3	29.5	28.6	27.8	27.1	**9**
10	60.8	59.6	58.4	57.3	56.1	55.0	53.8	52.7	51.6	50.5	49.4	48.3	47.3	46.2	45.1	44.1	43.1	42.1	41.1	40.1	39.1	38.1	37.2	36.2	35.3	34.4	33.4	32.5	31.7	30.8	29.9	**10**
11	65.6	64.3	63.0	61.8	60.5	59.3	58.1	56.9	55.7	54.5	53.3	52.2	51.0	49.9	48.8	47.6	46.5	45.4	44.3	43.3	42.2	41.2	40.1	39.1	38.1	37.1	36.1	35.1	34.1	33.1	32.2	**11**
12	69.8	68.4	67.1	65.7	64.4	63.1	61.8	60.5	59.2	58.0	56.7	55.5	54.2	53.0	51.8	50.6	49.4	48.2	47.1	45.9	44.8	43.6	42.5	41.4	40.3	39.2	38.1	37.1	36.0	35.0	33.9	**12**
13	73.4	72.0	70.6	69.1	67.7	66.3	65.0	63.6	62.2	60.9	59.5	58.2	56.9	55.6	54.3	53.0	51.7	50.5	49.2	48.0	46.8	45.5	44.3	43.1	42.0	40.8	39.6	38.5	37.3	36.2	35.1	**13**
14	76.5	75.0	73.5	72.0	70.5	69.0	67.6	66.1	64.7	63.2	61.8	60.4	59.0	57.6	56.2	54.9	53.5	52.2	50.8	49.5	48.2	46.9	45.6	44.3	43.1	41.8	40.6	39.3	38.1	36.9	35.7	**14**
15	79.0	77.4	75.9	74.3	72.7	71.1	69.6	68.1	66.5	65.0	63.5	62.0	60.6	59.1	57.6	56.2	54.7	53.3	51.9	50.5	49.1	47.7	46.3	45.0	43.6	42.3	41.0	39.7	38.4	37.1	35.8	**15**
16	81.0	79.3	77.7	76.0	74.4	72.7	71.1	69.5	67.9	66.3	64.7	63.1	61.5	60.0	58.4	56.9	55.4	53.9	52.4	50.9	49.4	48.0	46.5	45.1	43.6	42.2	40.8	39.4	38.0	36.6	35.3	**16**
17	82.5	80.7	78.9	77.2	75.5	73.7	72.0	70.3	68.6	66.9	65.3	63.6	62.0	60.3	58.7	57.1	55.5	53.9	52.3	50.8	49.2	47.7	46.1	44.6	43.1	41.6	40.1	38.6	37.1	35.7	34.2	**17**
18	83.3	81.5	79.6	77.8	76.0	74.2	72.4	70.6	68.8	67.1	65.3	63.6	61.9	60.1	58.4	56.7	55.1	53.4	51.7	50.1	48.4	46.8	45.2	43.6	42.0	40.4	38.8	37.3	35.7	34.2	32.6	**18**
19	83.6	81.7	79.8	77.9	76.0	74.1	72.2	70.3	68.5	66.6	64.8	63.0	61.2	59.4	57.6	55.8	54.0	52.3	50.5	48.8	47.1	45.4	43.7	42.0	40.3	38.6	37.0	35.3	33.7	32.1	30.5	**19**
20	83.4	81.4	79.4	77.4	75.4	73.4	71.5	69.5	67.6	65.7	63.7	61.8	60.0	58.1	56.2	54.3	52.5	50.6	48.8	47.0	45.2	43.4	41.6	39.8	38.1	36.3	34.6	32.9	31.2	29.4	27.7	**20**
21	82.6	80.5	78.4	76.3	74.3	72.2	70.2	68.2	66.1	64.1	62.1	60.1	58.2	56.2	54.2	52.3	50.4	48.4	46.5	44.6	42.8	40.9	39.0	37.2	35.3	33.5	31.7	29.8	28.0	26.3	24.5	**21**
22	81.2	79.1	76.9	74.7	72.6	70.5	68.3	66.2	64.1	62.0	59.9	57.9	55.8	53.8	51.7	49.7	47.7	45.7	43.7	41.7	39.7	37.8	35.8	33.9	32.0	30.1	28.2	26.3	24.4	22.5	20.6	**22**
23	79.3	77.1	74.8	72.6	70.4	68.1	65.9	63.7	61.5	59.4	57.2	55.1	52.9	50.8	48.7	46.6	44.5	42.4	40.3	38.2	36.2	34.1	32.1	30.1	28.1	26.1	24.1	22.1	20.2	18.2	16.3	**23**
24	76.9	74.5	72.2	69.9	67.6	65.3	63.0	60.7	58.4	56.2	53.9	51.7	49.5	47.3	45.0	42.9	40.7	38.5	36.4	34.2	32.1	29.9	27.8	25.7	23.6	21.6	19.5	17.4	15.4	13.3	11.3	**24**
25	73.8	71.4	69.0	66.6	64.2	61.8	59.5	57.1	54.7	52.4	50.1	47.8	45.5	43.2	40.9	38.6	36.3	34.1	31.8	29.6	27.4	25.2	23.0	20.8	18.6	16.5	14.3	12.2	10.1	7.9	5.8	**25**
26	70.3	67.8	65.3	62.8	60.3	57.8	55.4	52.9	50.5	48.1	45.7	43.3	40.9	38.5	36.1	33.8	31.4	29.1	26.8	24.5	22.2	19.9	17.6	15.3	13.1	10.8	8.6	6.4	4.2	2.0	-0.2	**26**
27	66.1	63.5	61.0	58.4	55.8	53.3	50.8	48.2	45.7	43.2	40.7	38.2	35.8	33.3	30.9	28.4	26.0	23.6	21.2	18.8	16.4	14.0	11.7	9.3	7.0	4.6	2.3	0.0	-2.3	-4.6	-6.8	**27**
28	61.4	58.8	56.1	53.5	50.8	48.2	45.6	43.0	40.4	37.8	35.2	32.6	30.1	27.5	25.0	22.5	20.0	17.5	15.0	12.5	10.0	7.6	5.1	2.7	0.3	-2.1	-4.5	-6.9	-9.3	-11.6	-14.0	**28**
29	56.2	53.4	50.7	48.0	45.2	42.5	39.8	37.1	34.5	31.8	29.1	26.5	23.8	21.2	18.6	16.0	13.4	10.8	8.3	5.7	3.2	0.6	-1.9	-4.4	-6.9	-9.4	-11.9	-14.4	-16.8	-19.3	-21.7	**29**
30	50.4	47.6	44.7	41.9	39.1	36.3	33.5	30.8	28.0	25.2	22.5	19.8	17.1	14.3	11.6	9.0	6.3	3.6	1.0	-1.7	-4.3	-6.9	-9.5	-12.1	-14.7	-17.3	-19.9	-22.4	-24.9	-27.5	-30.0	**30**
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	

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Chapter 2

Competition and Innovation: An Experimental Investigation

joint with Dario Sacco and Armin Schmutzler

1 Introduction

Simple two-stage games are often used to derive predictions about the effects of increasing competition on cost-reducing investments.[1] Testing such predictions in the field is very difficult, and the literature comes to ambiguous conclusions.[2] Therefore, this paper uses laboratory experiments to explore whether at least the basic strategic effects identified in the theoretical models are present.

We consider four different games where two or four firms choose a cost-reducing investment before they engage in Cournot or Bertrand competition with homogeneous goods. Thus we can explore how increasing competition by increasing the number of players and by switching from Cournot to Bertrand competition affects investments.[3] To understand better what drives the results, we not only considered treatments with the two-stage structure of the underlying game, but we also analyzed one-stage treatments where subjects' investment decisions automatically result in the payoffs of the ensuing product-market subgame. This allows us to investigate whether deviations from the equilibrium investments in the two-stage

[1] Schmutzler (2010) and Vives (2008) synthesize the existing literature.

[2] See the references at the end of this section.

[3] In a related paper, Sacco and Schmutzler (2011) analyze the effects of increasing competition by changing the degree of substitutability in a differentiated product market. They expose a U-shaped relation in the underlying Shubik-Levitan model, and they provide weak experimental evidence in favor of such a relation.

game are driven exclusively by expected deviations in the product-market game. Our analysis leads to the following main insights.

(1) Investments decrease as the number of players increases.

(2) For a switch from Cournot to Bertrand competition, the observed effect on investments is positive.

(3) The positive investment effect of moving from Cournot to Bertrand competition arises even in the four-player case, where the predicted effect is negative.

(4) Even though all three results just described arise both for the one-stage and two-stage treatments, the positive effect of moving from Cournot to Bertrand is more pronounced for the two-stage treatments.

Result (1) confirms what has been observed by other authors in stochastic static and dynamic patent races (Isaac and Reynolds 1988, 1992). Cournot investment games have been studied by Suetens (2005), but only for duopoly markets.[4] Thus, the number effects of competition on investment have not been studied in a Cournot setting.[5]

The remaining results have not been observed elsewhere. Except for the unpublished working paper of Sacco and Schmutzler (2008) and Chapter 3, we are not aware of any other contribution that deals with investment games under homogeneous Bertrand competition,[6] let alone with a comparison between Cournot and Bertrand investment games.[7]

Result (3) has also not been observed so far, but it is related to familiar overbidding results in the context of all-pay auctions, which are similar to Bertrand investment games.[8] Result (4) is of more general methodological value: It shows that, to understand behavior in two-stage games, it is useful to consider both the

[4]Suetens (2005) focuses on the differences between investments and the Nash equilibrium, and specifically on the role of knowledge spillovers in this context. In Suetens (2008) the focus is on RJVs and their effect on price collusion in Bertrand competition with product differentiation. Again she only considers duopoly markets and the effects of increasing competition are not a matter of concern.

[5]Importantly, note that our analysis is distinct from the more familiar analysis of number effects in Cournot oligopolies (Huck et al. 2004; Orzen 2008). This literature deals with the effects on prices and quantities rather than on investments.

[6]Sacco and Schmutzler (2008) consider the reduced one-stage version of a two-stage Bertrand game, where investments precede price competition. It shows that overinvestment is substantial. Overinvestment is also observed in Chapter 3 where both stages are played out, but they focus on the incentive effects of political instruments on investment. However, both papers do not deal with the effects of increasing competition.

[7]Suetens and Potters (2007) compare prices and outputs in Bertrand and Cournot games, but not investments.

[8]See Section 5 for a more careful discussion.

full two-stage game and the reduced one-stage version. In this fashion, one can identify the sources of deviations from the first-stage equilibrium choices more readily. Specifically, we show that first-stage overinvestment in the Bertrand case tends to go hand in hand with above-equilibrium prices in the second stage.

We see our experimental research as complementary to the existing field research, which comes to ambiguous conclusions about the effects of competition on investment. Broadly speaking, this ambiguity may reflect either small differences in the strategic environment or endogeneity problems. As to the former, Schmutzler (2010) emphasizes how the predicted effect of competition on investment depends on modeling details, which would suggest that ambiguous empirical results are merely the confirmation of ambiguous predictions. As to the endogeneity problem, it looms large in the early literature, surveyed in Cohen and Levin (1989). While this literature regarded market structure as an explanatory variable, the causality might run in the opposite direction.[9] Innovation may influence market structure because R&D involves fixed costs, because it affects the pattern of firm growth in an industry or changes the efficient scale of production. This endogeneity problem has been taken into account to some extent by the more recent literature. Nevertheless this literature is not very conclusive. For instance, Nickell (1996) obtains a positive effect of competition on investments. In Aghion, Bloom, Blundell, Griffith, and Howitt (2005), an inverted-U relationship between intensity of competition and investments arises. An experimental analysis addresses both problems: It allows us to delineate a setting in which the theoretical predictions are clear and there are no endogeneity problems.

The paper is structured as follows. Section 2 contains the theoretical framework. Sections 3-5 describe the experimental design and results. Section 6 concludes.

2 The Model

We analyze static two-stage games, where firms $i = 1, ..., I$ first invest in R&D and then compete in the product market. The demand function for the homogeneous product is given by $D(p) = a - p$, with $a > 0$. All firms i are identical ex-ante, with constant marginal costs $c > 0$. In the first stage, firms simultaneously choose R&D investments $Y_i \in [0, c)$, resulting in marginal costs $c_i = c - Y_i$. The cost of R&D is given by kY_i^2, where $k > 0$. In the second stage, firms simultaneously choose quantities (Cournot competition) or prices (Bertrand competition).

[9] For an introduction to more recent evidence on that matter, see Gilbert (2006).

2.1 Cournot Competition

For the Cournot case, backward induction shows that the net payoff function of firm i in the first stage is given by

$$\Pi_i(Y_1, ..., Y_I, \alpha, k) = \left(\frac{\alpha + IY_i - \sum_{i \neq j} Y_j}{I+1} \right)^2 - kY_i^2, \tag{1}$$

where $\alpha \equiv a - c$ represents the demand parameter.[10]

The gross payoff of firm i, that is, the first term on the right-hand side of (1), depends positively on its own investment and the demand parameter, and negatively on the investments of the other firms. The following result is immediate[11]:

Proposition 2.1. *Under Cournot competition the symmetric pure-strategy Nash equilibrium investment levels are*

$$Y^C = \frac{\alpha I}{k(I+1)^2 - I}. \tag{2}$$

By (2), equilibrium investments are increasing in the demand parameter α, and decreasing in the cost parameter k and in the number of firms I.

2.2 Bertrand Competition

For Bertrand Competition, backward induction shows that the net payoff function of firm i can be written as a function of efficiency levels as follows:

$$\Pi_i(\cdot) = \begin{cases} (Y_i - Y_{-i}^m) D(c - Y_{-i}^m) - kY_i^2, & \text{if } Y_i > Y_{-i}^m \\ -kY_i^2, & \text{if } Y_i \leq Y_{-i}^m \end{cases}, \tag{3}$$

where $Y_{-i}^m = \max_{j \neq i} Y_j$. Compared to the Cournot case, competition is intense in the sense that a firm can achieve a positive gross payoff only by investing more than the highest investment of the others. If $Y_i > Y_{-i}^m$, maximizing (3) with respect to Y_i gives

$$\frac{\partial \Pi_i(\cdot)}{\partial Y_i} = D(c - Y_{-i}^m) - 2kY_i \equiv 0. \tag{4}$$

$Y_i \leq Y_{-i}^m$ can only be a best response if $Y_i = 0$ holds: If firm i does not invest more than all others, it gets a negative net payoff. In such a case the deviation to $Y_i = 0$ is profitable. The pure-strategy equilibrium is thus characterized as follows (Sacco and Schmutzler (2008), Prop. 7).

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[10] Here and in the following, we assume that $\alpha + IY_i - \sum_{i \neq j} Y_j \geq 0$.

[11] We assume that the second order condition holds, that is, $I^2/(I+1)^2 - k < 0$, which is fulfilled for arbitrary $I \geq 2$ if $k \geq 1$.

Proposition 2.2. *(i) Under Bertrand Competition, for $k > \frac{1}{2}$, there are multiple asymmetric pure-strategy equilibria with one firm investing $Y_i^B = \frac{\alpha}{2k}$ and firms $j \neq i$ investing $Y_j^B = 0$. (ii) There are no other pure-strategy equilibria.*

Proposition 2.2 implies that the average investments are $\overline{Y}^B = \frac{\alpha}{2kI}$, which is increasing in α, and decreasing in k and in I. It is unlikely that agents can coordinate on one of the asymmetric pure-strategy equilibria. We therefore refer to the following result of Sacco and Schmutzler (2008).

Proposition 2.3. *The investment game with Bertrand Competition has a symmetric mixed-strategy equilibrium, where firms mix between all strategies up to a cut-off level.*[12]

Of course, one may be concerned with the relevance of mixed-strategy equilibria in the context of an oligopoly with a small number of players. We clearly do not expect decision makers in firms to randomize deliberately. Also, the common justification that mixed-strategy equilibria describe behavior in large populations of players, each of which takes non-random decisions, makes no sense in our context. A more convincing a priori justification relies on standard purification arguments (Harsanyi, 1973).[13]

2.3 The Effects of Increasing Competition

We now consider the predicted effects of competition on investment.

Corollary 2.1. *(i) The average equilibrium investments are decreasing in I for both Bertrand and Cournot competition.*
(ii) Suppose that $k > \max\left\{\frac{1}{2}, \frac{I^2}{(I+1)^2}\right\}$. The average equilibrium investment for Cournot is higher than the average investment in each asymmetric pure-strategy equilibrium for Bertrand for $I \geq 3$. For $I = 2$, average investments are higher for Bertrand unless $k \leq 2$.

Though we cannot provide such results for the mixed-strategy equilibrium at this level of generality, a similar statement holds for the parameters we choose (see 3.2). Thus, except for the caveat for $I = 2$, for both concepts of competitiveness, an increase in competition reduces investment.

Both of these changes in the competitive environment have the common feature that they correspond to reductions in the mark-ups that firms can command in the product market equilibrium. To see the crucial difference, note that an increase in

[12] The game also has asymmetric mixed-strategy equilibria where some firms always play zero and others randomize.

[13] Specifically, one can consider a Bayesian game with a continuum of players with statistically independent types, reflecting small differences in payoffs. The mixed-strategy equilibrium of the complete information game is then close to the equilibria of nearby Bayesian games.

the number of competitors in a Cournot setting has a fairly smooth effect on the nature of competition. Most importantly, both firms can obtain positive profits before and after the change in competition. As one moves from Cournot to Bertrand, the change in the competitive environment is more dramatic: It is well known that at most one firm can obtain a positive profit in the Bertrand investment game when both firms choose equilibrium prices in the ensuing subgame; so that competition is of a winner-takes-all nature. Thus, without correct expectations about competitor investments players may easily take very bad decisions. The Bertrand game has multiple asymmetric pure-strategy equilibria, a symmetric mixed-strategy equilibrium and even asymmetric mixed-strategy equilibria. It is not obvious how players coordinate in a static setting. We use the mixed-strategy equilibria as the benchmark to predict equilibrium investments in the Bertrand game, whereas we resort to the symmetric pure-strategy equilibrium in the Cournot case.

3 Experimental Design

We now describe the treatments, the parameters and the hypotheses.

3.1 Treatments

We conducted eight treatments (see Table 1), which differed in the following three dimensions:

1. The number of players (two vs. four)
2. The mode of competition (Bertrand vs. Cournot)
3. The number of stages played out (one vs. two)

The need for the first two treatment variations is obvious given our questions of interest. The third point requires some clarification. To capture the models introduced in Section 2 accurately, the two-stage treatments are adequate and, arguably, they are also more realistic. However, in such treatments, there may be confusion about the source of possible deviations from the equilibrium in the investment game. Broadly, one can imagine two classes of deviations. First, subjects may be expecting non-equilibrium behavior in the product market stage.[14] For instance, they might believe that all parties (including themselves) collude below the equilibrium output in the Cournot game, in which case they should rationally choose lower than equilibrium investments in the first stage. Second, even when they do not expect

[14]Such deviations are known to arise both in the Bertrand (Dufwenberg and Gneezy 2007) and in the the Cournot case (Huck et al. 2004, and many others).

Table 1: Treatments

	Type of competition	
Number of players	Bertrand	Cournot
$I = 2$	B2, 2 sessions	C2, 2 sessions
$I = 4$	B4, 2 sessions	C4, 2 sessions

For each treatment we ran two sessions, one with one stage and one with two stages played out.

such deviations in the product market game, players may want to deviate from equilibrium investments for other reasons. For example, they might realize that investments involve negative externalities, and they may want to coordinate on lower investments that make all players better off.

To identify which of these two types of deviations arise, we conducted all treatments in two different versions which we call one- and two-stage treatments. In the latter, subjects play the product market game as well as the investment game. In the one-stage treatments subjects only choose investment levels, and payoffs for each choice of investments correspond to the payoffs in the equilibrium of the ensuing product market subgame by assumption. Thus deviations from equilibrium cannot result from expected deviations in the product market game. Thereby we can identify to which extent deviations in the two-stage game are attributable to each source of deviations.

3.2 Parameters and Predictions

We chose parameter values $\alpha = 30$ and $k = 3$. We restricted the strategy sets to $Y_i \in \{0, 1, ..., 9\}$. Restricting choices to discrete strategies had two main advantages. First, we could present information on payoffs (gross of investment costs) in simple matrices. Second, in this fashion, the integers no longer play the role of prominent numbers.

The downside is that the equilibria of the discrete game reflect the negative effect of increasing the number of players on investments only imperfectly. For some parameters, increases in the number of players have no effect. For instance, equilibrium investments are $(2, 2)$ for the two-player Cournot game and $(2, 2, 2, 2)$ for the four-player game. While the equilibria of the discrete game are the more natural benchmark for individual behavior given the discrete strategy sets, it will turn out to be instructive to compare *average* behavior with the corresponding continuous games. The equilibria for these games are $(2.4, 2.4)$ and $(1.69, 1.69, 1.69, 1.69)$, so that the investment effect of increasing the number of players is negative.

For Bertrand competition, there is no such problem: According to Proposition 2.2, there are asymmetric equilibria, each with one firm investing 5 and the other firm(s) 0. This holds both for the discrete and continuous strategy set. Moreover, using the formulas provided by Sacco and Schmutzler (2008), one can show that the two-player game has a symmetric mixed-strategy equilibrium (MSE) given by

$$(p_0, ..., p_9) = (0.1, 0.193, 0.187, 0.182, 0.176, 0.160, 0, 0, 0, 0)\,. \qquad (5)$$

For the four-player game, the symmetric MSE is given by

$$(p_0, ..., p_9) = (0.464, 0.2, 0.119, 0.088, 0.071, 0.057, 0, 0, 0, 0)\,. \qquad (6)$$

The expected investment levels (2.62 for the two-player and 1.27 for the four-player Bertrand game) are close to the average investments ($\overline{Y}^{B2} = 2.5$; $\overline{Y}^{B4} = 1.25$) of the pure-strategy equilibria.

Table 2 provides an overview of the equilibrium investments.

Table 2: Equilibria

	Equilibrium investment		
Model	discrete	continuous	mixed
Cournot $I = 2$	(2, 2)	(2.4, 2.4)	-
Cournot $I = 4$	(2, 2, 2, 2)	(1.69, 1.69, 1.69, 1.69)	-
Bertrand $I = 2$	(5, 0)	(5, 0)	(2.62, 2.62)
Bertrand $I = 4$	(5, 0, 0, 0)	(5, 0, 0, 0)	(1.27, 1.27, 1.27, 1.27)

For the mixed equilibria we show expected investment levels, see equations (5) and (6).

We use the equilibrium predictions to derive the following hypotheses about the effects of increasing competition.

Hypothesis 3.1. *Increasing competition in the sense of switching from two to four players has a non-positive effect on investments in the Cournot case and reduces investments in the Bertrand case.*

The *non-positive* effect on investments in the Cournot case is consistent with the prediction of no effect from the discrete game and of a negative effect from the continuous game.

Hypothesis 3.2. *Increasing competition in the sense of switching from Cournot to Bertrand competition increases investments in the two-player case and reduces investments in the four-player case.*

The two predictions of Hypothesis 3.2 can be derived by using the equilibria of the discrete game as well as those of the continuous game. They hold for the asymmetric pure-strategy equilibria and the symmetric MSE.

3.3 Subjects and Payments

The experimental sessions were conducted between November 2008 and February 2009 at the University of Zurich. The participants were undergraduate students.[15] We implemented four sessions with Bertrand treatments, and four with Cournot treatments (see Table 1). Two of the Bertrand and two of the Cournot sessions were two-player treatments. In each session there were 20 periods. No subject participated in more than one session. The four-player sessions had 32 subjects; each two-player session had 36 subjects. The 36 (32) subjects of the two-player (four-player) treatments were randomly divided in matching groups of four (eight) subjects each at the beginning of the experiment. Within the matching groups we applied the stranger design, i.e. randomly rematched subjects into groups of two (four) after each period.[16] Thus, we obtained nine (four) independent observations per two (four)-player session. Sessions lasted about 90 minutes each.

At the end of each period, subjects were informed about the investment of the other subject(s) in their group and their own net payoff for that period. When the second stage was played out, they were informed about the investment of the other subject(s) in their group before choosing price or quantity and after the second stage they also learned the price or the quantity decision of the other group member(s). Participants received an initial endowment of CHF 35 (≈EUR 23).[17] Average earnings including the endowment were between CHF 30 (≈EUR 20) and CHF 36 (≈EUR 23) for the Bertrand sessions and between CHF 39 (≈EUR 26) and CHF 49 (≈EUR 33) for the Cournot sessions. The experiment was programmed and conducted with the software z-Tree (Fischbacher 2007) and subjects were recruited using ORSEE (Greiner 2004).

4 Results

In Section 4.1 we provide a brief overview of the results. In Section 4.2, we look at our hypotheses in more detail.

[15] We did not exclude any disciplines. We had students of law, engineering, psychology, economics etc.

[16] Thanks to the matching group approach, we obtain sufficiently many independent observations while reducing the possibility of repeated game behavior. Nevertheless, subjects may "learn" from the past prices/quantities chosen by the other players in their matching groups. Modeling how the firms arrive at their beliefs about the other player's future prices when they choose investments is beyond the scope of this paper, however.

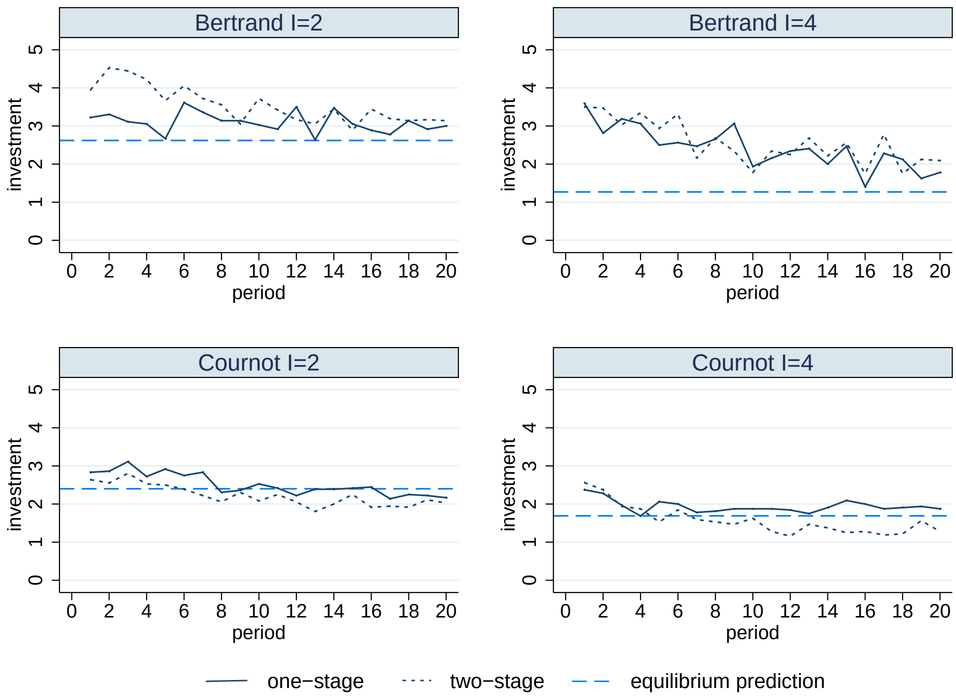
[17] The instructions of all treatments are available online as supplementary material to Darai, Sacco, and Schmutzler (2010).

4.1 Overview

Here and in the following, we always use matching group averages as independent observations. Kruskal-Wallis tests reveal that we can reject the hypothesis that the investment levels of all treatments, of all one-, or of all two-stage treatments are drawn from the same population.[18]

Figure 1 illustrates how investments vary across treatments. Each panel contains the average per-period investments for one of the four cases, distinguishing between the one-stage and the two-stage treatments. It also shows the equilibrium investments.[19] Based on this descriptive evidence, we arrive at the following tentative conclusions.

Figure 1: Average investment per period



1. Increasing the number of players leads to lower average investments in the Cournot and the Bertrand case.[20]

[18]The null hypothesis of no differences is rejected with a p-value of 0.000, if all treatments are considered. If we take only the one (two)-stage treatments into account the p-value is 0.006 (0.000).

[19]In the Cournot case, we depict the equilibria of the continuous game; recall that the equilibria for the discrete game are $(2,2)$ and $(2,2,2,2)$, respectively.

[20]These results are supported by pairwise Mann-Whitney-U tests. We find significant differences between C2 and C4 as well as between B2 and B4. One-tailed tests reject the null hypothesis of

2. Moving from Cournot to Bertrand competition leads to greater average investments for the two-player and four-player treatments.[21]

3. For the four-player case, the positive effect of moving from Cournot to Bertrand competition holds even though the predicted effect is negative.[22]

4. The positive investment effect of moving from Cournot to Bertrand competition is more pronounced in the two-stage treatments.[23]

4.2 Comparative Statics

We now analyze the comparative statics effects in more detail.

4.2.1 Number Effects

To investigate the number effects, we consider OLS models[24] of all Cournot treatments as well as of the one- and two-stage treatments separately; similarly for the Bertrand case. The model is given by

$$y_t^i = \beta_0 + \beta_1 \delta_{I4}^i + \sum_{s=1}^{3} \beta_{s+1} \delta_{Ps}^i + \beta_5 \delta_{one-stage}^i + \beta_6 \delta_{I4*one-stage}^i + e_t^i, \tag{7}$$

where δ_{I4}^i is a dummy variable for intense competition (four players rather than two), and δ_{Ps}^i are dummy variables for the first, second, and third quarter of periods. When we use the data of all treatments, we consider two additional dummy variables $\delta_{one-stage}^i$ which is equal to one for the one-stage treatments and $\delta_{I4*one-stage}^i$ which captures the interaction effect between the number of players and the type of treatment.

no differences in average investments in favor of higher investment levels in C2 (B2) than in C4 (B4) at a p-value of 0.025 (0.048) for the one-stage treatments, and respectively at a p-value of 0.010 (0.003) for the two-stage treatments. Pooling the data of the one- and two-stage treatments results a p-value of 0.001 (0.000).

[21]The result for the two-player case is supported by a one-tailed Mann-Whitney-U test for the two-player one-stage (p=0.005) and two-stage treatments (p=0.000) and for the pooled data (p=0.000). For the four-player case, a two-tailed Mann-Whitney-U test does not reject the hypothesis of no differences in investment levels between the two four-player one-stage treatments with a p-value of 0.200. For the two-stage treatments it rejects the null with a p-value of 0.029 and for the pooled data with a p-value of 0.001 if we pool the data. However the mean ranks are always higher in B4 than in C4.

[22]This predicted negative effect holds not only for the equilibrium of the continuous Cournot game depicted Figure 1, but also for the equilibrium of the discrete Cournot game, where average investments are 2 and thus higher than in the Bertrand MSE (1.27).

[23]In the C2 one (two)-stage treatment we observe average investment of 2.51 (2.22) and 1.94 (1.57) in the C4 treatment. However, in the B2 one (two)-stage treatments we observe average investment of 3.10 (3.55) and 2.42 (2.56) for B4 treatments.

[24]We correct the standard error for matching group clusters in all OLS models presented in the following.

Table 3: Number effects in Cournot and Bertrand treatments

investment	(1-stage)		(2-stage)		(1- and 2-stage)	
Cournot Treatments						
I4	-0.575***	(0.186)	-0.648***	(0.184)	-0.648***	(0.180)
$P_{1st-quarter}$	0.415**	(0.138)	0.682***	(0.149)	0.549***	(0.107)
$P_{2nd-quarter}$	0.141	(0.103)	0.265***	(0.068)	0.203***	(0.063)
$P_{3rd-quarter}$	0.053	(0.069)	0.047	(0.044)	0.050	(0.040)
one-stage					0.296	(0.178)
I4*one-stage					0.073	(0.256)
constant	2.362***	(0.112)	1.970***	(0.106)	2.018***	(0.120)
R^2	0.082	(N=1360)	0.113	(N=1360)	0.114	(N=2720)
Bertrand Treatments						
I4	-0.675**	(0.293)	-0.992***	(0.205)	-0.992***	(0.201)
$P_{1st-quarter}$	0.626*	(0.313)	1.044***	(0.178)	0.835***	(0.178)
$P_{2nd-quarter}$	0.491*	(0.275)	0.382**	(0.131)	0.437***	(0.150)
$P_{3rd-quarter}$	0.294**	(0.100)	0.135	(0.173)	0.215**	(0.099)
one-stage					-0.451**	(0.207)
I4*one-stage					0.317	(0.351)
constant	2.744***	(0.161)	3.158***	(0.149)	3.177***	(0.172)
R^2	0.026	(N=1360)	0.078	(N=1360)	0.051	(N=2720)

Standard errors in parentheses are corrected for matching group clusters.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 3 shows that the estimated coefficient for β_1 in the one-stage Cournot model is -0.575 and highly significant. For the two-stage treatments, we obtain a highly significant β_1 of -0.648. Thus, the comparative statics are essentially the same in one-stage and two-stage treatments.[25] This result is supported by an insignificant stage and interaction effect if we pool the data. Finally, for both the one-stage and the two-stage treatments, we see that investments decrease over time.

For the Bertrand treatments, the effect of the number of players on investments has the predicted sign and is significant for the one– and two-stage treatments.[26] But the stage effect in the third Column is significant and negative. The interaction effect is insignificant which means that the number effect does not differ between the one- and two-stage treatments. Again we find that investment levels are significantly higher in earlier periods.

Summing up, we obtain the following confirmation of Hypothesis 3.1.

Result 4.1. *For Cournot and Bertrand competition, investments are higher for two than for four players. Even though investment levels in one-stage and two-stage*

[25] Using a t-test, we cannot reject the null hypothesis of no difference between the two estimated coefficients ($|t| = 0.2790$).

[26] Running a t-test reveals that the difference between the two estimated coefficients is not significant ($|t| = 0.8865$).

treatments differ, there is no significant difference in the size of the number effect across treatments.

4.2.2 Cournot versus Bertrand

We now consider the effect of moving from soft Cournot to intense Bertrand competition, considering OLS models of the one-stage and two-stage treatments separately and jointly. The models include $\delta^i_{Bertrand}$ as a dummy variable for intense (Bertrand) competition and dummy variables δ^i_{Ps} for the first, second, and third quarter of periods. $\delta^i_{one-stage}$ is a dummy variable for the one-stage treatment and $\delta^i_{Bertrand*one-stage}$ is the interaction effect between the type of competition and treatment.

$$y^i_t = \beta_0 + \beta_1\delta^i_{Bertrand} + \sum_{s=1}^{3}\beta_{s+1}\delta^i_{Ps} + \beta_5\delta^i_{one-stage} + \beta_6\delta^i_{Bertrand*one-stage} + e^i_t. \quad (8)$$

Table 4: Effects of the type of competition in two- and four-player treatments

investment	(1-stage)		(2-stage)		(1- and 2-stage)	
Two-Player Treatments						
Bertrand	0.583***	(0.170)	1.331***	(0.217)	1.331***	(0.213)
$P_{1st-quarter}$	0.386*	(0.199)	0.783***	(0.201)	0.585***	(0.144)
$P_{2nd-quarter}$	0.311	(0.215)	0.317**	(0.123)	0.314**	(0.122)
$P_{3rd-quarter}$	0.147**	(0.067)	0.033	(0.129)	0.090	(0.072)
one-stage					0.296	(0.177)
Bertrand*one-stage					-0.747***	(0.271)
constant	2.303***	(0.138)	1.935***	(0.126)	1.971***	(0.131)
R^2	0.028	(N=1440)	0.185	(N=1440)	0.094	(N=2880)
Four-Player Treatments						
Bertrand	0.483	(0.310)	0.986***	(0.172)	0.986***	(0.166)
$P_{1st-quarter}$	0.672*	(0.298)	0.953***	(0.122)	0.813***	(0.160)
$P_{2nd-quarter}$	0.322	(0.227)	0.331***	(0.076)	0.327**	(0.115)
$P_{3rd-quarter}$	0.203	(0.128)	0.156	(0.123)	0.180*	(0.086)
one-stage					0.369*	(0.186)
Bertrand*one-stage					-0.503	(0.342)
constant	1.640***	(0.190)	1.210***	(0.142)	1.241***	(0.150)
R^2	0.030	(N=1280)	0.088	(N=1280)	0.060	(N=2560)

Standard errors in parentheses are corrected for matching group clusters.
$^{*}\ p < 0.1$, $^{**}\ p < 0.05$, $^{***}\ p < 0.01$

Table 4 summarizes the results. In all three models, the effect of competition on investment is positive and highly significant for the two-player case. In the four-player case the result is positive and significant for the two–stage treatments.[27]

[27]The period dummies show that investments decrease significantly as time goes by, independent of the data selection.

Result 4.2. *Mean investments are higher for the Bertrand game than for the corresponding Cournot games.*

In the four-player game this contradicts the equilibrium prediction that investments are lower for the Bertrand case.[28]

Result 4.3. *In the four-player case, the positive investment effect of moving from Cournot to Bertrand competition arises even though the predicted effect is negative.*

Next, compare one-stage and two-stage treatments. In the two-player as well as the four-player case, β_1 is larger for the two-stage treatments. The difference is significant for the two-player case ($|t| = 2.7135$), but not for the four-player case ($|t| = 1.4188$). This is also shown by the highly significant interaction term in the two-player case, i.e. the effect of Bertrand competition on investment is different for one- and two-stage treatments. With this qualification, we summarize:

Result 4.4. *The effect of moving from Cournot to Bertrand competition tends to be more positive for two-stage than for one-stage treatments.*

5 Understanding Overinvestment

We now investigate why the effect of moving from Cournot to Bertrand competition (i) is positive even when the prediction is that it is negative and (ii) is more pronounced in the two-stage treatments. We consider the OLS regression

$$\triangle y_t^i = y_t^i - y_t^{i*} = \beta_0 + e_t^i, \tag{9}$$

with y_t^{i*} standing for the predicted investment. If subjects invest according to the prediction, the estimated constant β_0 should be zero. The results for all treatments are presented in Table 7 in Appendix A.2.

The most important observation is the highly significant overinvestment in all two-and four-player Bertrand treatments. The overinvestment is significantly higher ($|t| = 2.108$) in the two-player two-stage treatments than in the one-stage treatments and significantly higher ($|t| = 2.105$) in the one-stage four-player than in the one-stage two-player treatments. The Cournot case essentially confirms the equilibrium prediction for the continuous model (see Table 3), whereas in the two-player discrete model there is overinvestment. The fact that the continuous model is a better predictor for average investments than the discrete model is worth emphasizing. To understand why the switch from Cournot to Bertrand tends to have a strong

[28]The predicted effect is negative: In the continuous game, the effect is 1.27-1.69=-0.42; in the discrete game it is 1.27-2=-0.73.

positive effect on investments, however, one mainly has to find out what lies behind the overinvestment in the Bertrand case. Further, one needs to understand why the overinvestment is more pronounced for the two-stage treatments.

Before we deal with these issues, note the relation between our overinvestment and the overbidding observations that have emerged in the literature on all-pay auctions. In a Bertrand investment game, even when all players invest a positive amount, only one player can earn positive profits if second-period equilibrium prices are set. However, contrary to standard all-pay auctions, the size of the bids affects not only the chances of winning, but also the prize. In particular, at least in the one-stage version, when the difference to the second-highest bid is close to zero, so is the winner's prize. In spite of these differences in the strategic setting, our overinvestment results are similar to the overbidding that arises in fixed-prize all-pay auctions.[29]

5.1 Reasons for Overinvestment

To understand overinvestment in the Bertrand case, consider the following evidence.

(1) Investments decrease strongly over time.

(2) There is substantial cross-player heterogeneity.

(3) In the four player-treatments, players obtain negative profits on average in all periods, but the losses are decreasing over time. In the two-player treatments, average profits are mostly positive.

(4) Compared to the MSE, the overinvestment comes mainly from too low weight on low positive strategies rather than too low weight on zero.

Point (1) has already been made in Section 4.2.

Point (2) is illustrated in Figure 2. This figure is a histogram of average per-player investments in the four Bertrand treatments. The heterogeneity across players is substantial.[30] As to (3), consider Figure 3, which shows how profits developed over times for the one- and two-stage case. The differences between the two-player and the four-player case are evident.[31]

[29]Most closely related is Gneezy and Smorodinsky (2006) who consider symmetric all-pay auctions with 4, 8, and 12 players and also observe overinvestment. Like us, these authors obtain overbidding that diminishes over time, but remains substantial even in later periods. See also Davis and Reilly (1998).

[30]A figure with all individual investment paths (see Figure 5 in Appendix A.1) reveals substantial variety in another dimension: A considerable fraction of the players had one or two preferred investment choices that were chosen at least half the time. Almost as many players hardly ever chose the same investment level twice in a row.

[31]A two-tailed Mann-Whitney-U test rejects the null hypothesis of no differences between the one- and two-stage two-player treatments ($p = 0.000$), but the test cannot reject the null hypothesis in the four-player case ($p = 0.200$).

Figure 2: Average observed investment per subject for all Bertrand treatments

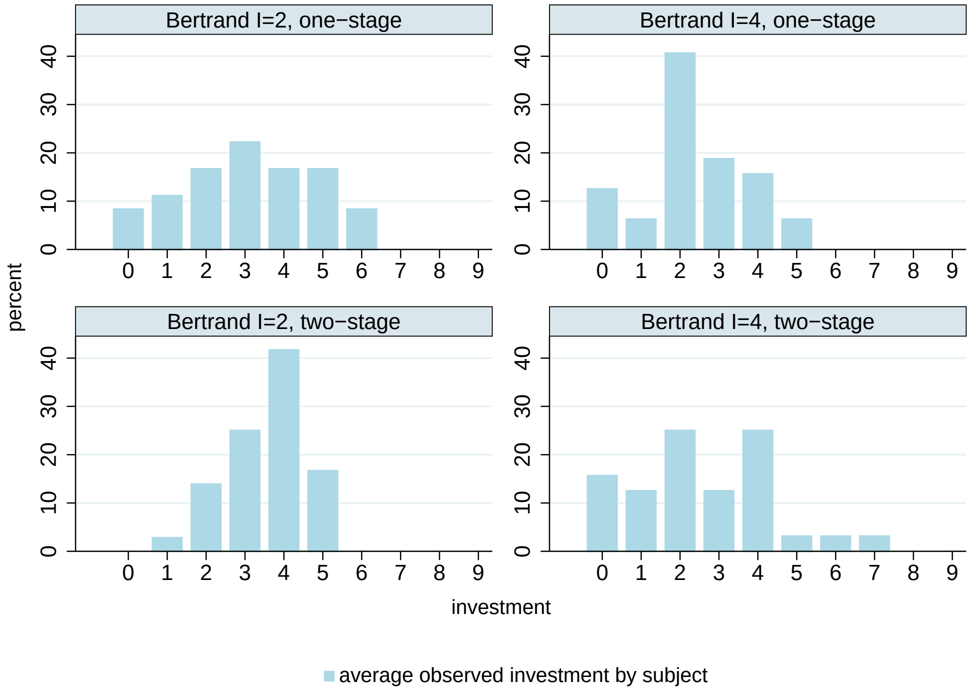


Figure 4 in Appendix A.1 confirms (4). In all treatments, subjects choose 1 and 2 much less frequently than in the MSE. The differences for zero investments are much smaller, and in one case (B2, one-stage) there are more zero investments than predicted by the MSE.

Our observations suggest a number of possible explanations for the overinvestment, all of which would apply both in the one-stage and the two-stage treatments.

1. *Joy of winning*: Subjects do not care exclusively about monetary payoffs, but derive an independent benefit from winning the game.

2. *Efficiency considerations*: Subjects deviate from equilibrium in order to come closer to joint-payoff maximization.[32]

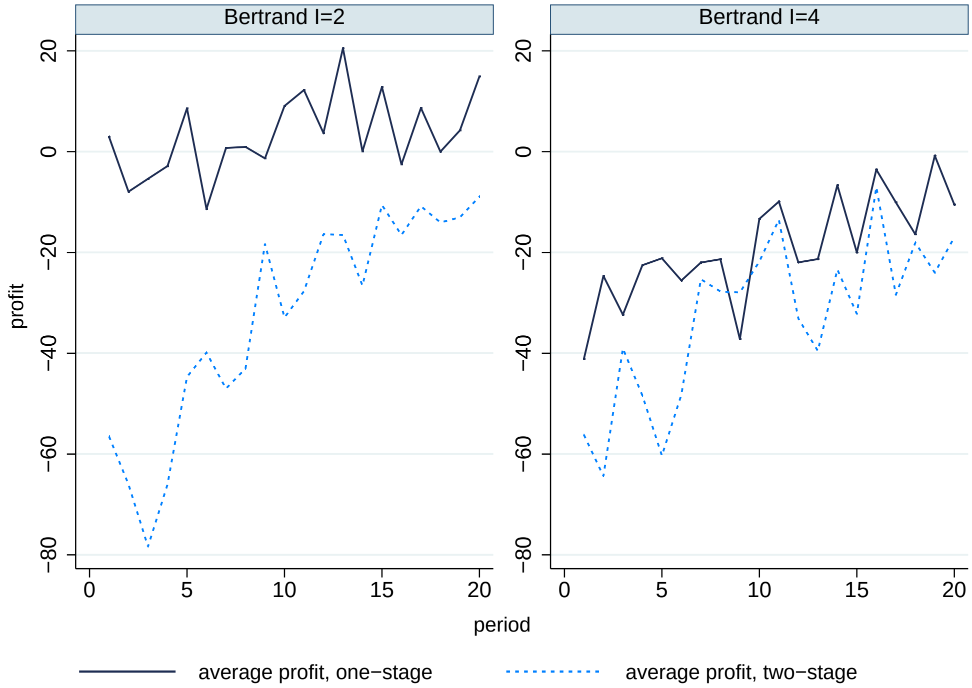
3. *Reputation effects*: Subjects hope to induce others to refrain from investing.

4. *Confusion*: Subjects are at least initially unaware of the high risk of making losses with high investment choices.

5. *Optimism*: Subjects are aware of the possible losses, but overestimate the chances that others choose lower investments.

[32]See, e.g., Engelmann and Strobel (2004).

Figure 3: Average profits over time of all Bertrand treatments



Given the heterogeneity of individual profiles, it seems unlikely that a single explanation applies to all players. *Joy of winning*, for instance, is consistent with the observation that subjects tend not to choose low investment levels if they invest at all.[33] However, because of the substantial reductions in investments over time,[34] joy of winning cannot explain all observations. *Efficiency considerations* are not an entirely convincing explanation either. At least for $I = 4$, the deviations from equilibrium reduce joint profits (which are zero in expectation in the MSE). For $I = 2$, however, in most periods, average profits are positive, so that subjects indeed come closer to joint-profit maximization.

Among the other explanations, the appeal of *reputation effects* is limited: player identities were not common knowledge. The other explanations all have some merits. Players invest a lot and earn negative profits in early periods, which is consistent both with *confusion* and excessive *optimism* that fade away over time. Also, it is suggestive that these effects are stronger in the four-player case, where the strategic uncertainty is compounded by the fact that three opponents are present in each period. Finally, as Figure 4 in Appendix A.1 shows, 10-15 % of the investments in all

[33] This argument is closely related to Sheremeta (2010) who allows for joy of winning in the utility function in an analysis of contests and provides experimental evidence for it.

[34] See regression results in Section 4.2.

Bertrand treatments are weakly dominated strategies (6 or higher), also suggesting some degree of confusion.

Although we can rule out that overinvestment results *exclusively* from anticipated deviations in the two-stage game, we still have to explain why the comparative-statics effect is more pronounced in the two-stage case than in the one-stage case.

5.2 The Role of the Second Stage

In the four-player games, averaging over all subgames, the observed output in the Bertrand (Cournot) case is only 1% (4%) lower than predicted.

For arbitrary investment decisions, the subgame equilibrium for Bertrand competition leads to higher market outputs than for Cournot competition. Consistent with this prediction, market outputs are higher in the Bertrand treatments than in the Cournot treatments, after controlling for average investments.[35] There are 14 different average investment levels that arise both in the Bertrand and the Cournot case. In 12 of these cases, the Bertrand outputs are higher than the Cournot outputs. Nevertheless, outputs tend to be lower than in equilibrium in the Bertrand treatment.

Analyzing individual behavior in the second stage, however, is more informative than considering only aggegate behavior. The key insight is that deviations from equilibrium ("collusion") in the second stage have different effects on the first period actions in the Cournot and in the Bertrand cases. In the Cournot case, collusion means that subjects choose lower outputs than in equilibrium in the second stage. Anticipating this, the value of investment is lower than it would be with equilibrium outputs. Thus, if subjects plan to set low outputs, they invest less in the two-stage game than in the one-stage version.

In the Bertrand case on which we focus here, the role of the second stage is much more subtle. A firm always runs the risk that there is another firm with a lower price, so that investments may be useless. Its willingness to invest will depend on how it perceives this risk – a firm will invest only if it is sufficiently confident that its competitors will not set lower prices than itself. Modeling how the firm arrives at its beliefs about the other players' future prices when it chooses investments is beyond the scope of this paper. But suppose there is some exogenous difference in the firms' "optimism". Optimistic firms believe that their competitors will not set prices aggressively, and they will therefore put a high probability on the chance of winning even with a substantial own mark-up. Firms that are more optimistic than others – for whatever reason – should thus set high prices (because they expect to

[35]In the Bertrand case (not in the Cournot case), the average equilibrium outputs may depend on the precise investment profile rather than merely on average investments. A clean comparison of market outputs would therefore condition on investment profiles rather than on averages. However, there are very few investment vectors that were chosen both in the Cournot and in the Bertrand treatments, so that this approach is not informative.

get away with it) and choose high investments (because they put a high probability on winning in spite of high prices).

Table 5: Deviation from the equilibrium price p^* in Bertrand two-stage treatments

	$c_i < \min\{c_{-i}\}$	$c_i = \min\{c_{-i}\}$	$c_i > \min\{c_{-i}\}$	$\sum$
Two-Player Treatment				
$p_i < p^*$	16%	4%	11%	12%
$p_i = p^*$	31%	64%	34%	39%
$p_i > p^*$	53%	32%	54%	49%
N	287	146	287	720
Four-Player Treatment				
$p_i < p^*$	12%	8%	7%	8%
$p_i = p^*$	28%	64%	54%	49%
$p_i > p^*$	60%	28%	39%	43%
N	139	50	451	640

Note: p^* comprises both the continuous and the discrete equilibrium.

Closer analysis of the data shows that this is precisely what happens. To see this, first consider Table 5 which shows that prices above the subgame equilibrium p^*[36] are indeed quite common.[37] In particular, 53% (60%) of the firms with the lowest marginal costs set prices above p^* in the two (four)-player treatment.

Table 6: Average investment in Bertrand two-stage treatments

	$c_i < \min\{c_{-i}\}$	$c_i = \min\{c_{-i}\}$	$c_i > \min\{c_{-i}\}$	$\sum$
Two-Player Treatment				
$p_i \leq p^*$	4.07	3.38	1.54	2.98
$p_i > p^*$	5.22	4.32	3.01	4.13
Four-Player Treatment				
$p_i \leq p^*$	4.78	2.81	0.34	1.25
$p_i > p^*$	6.36	4.93	3.29	4.32

Note: p^* comprises both the continuous and the discrete equilibrium.

Table 6 elaborates on this by giving the average investments both for the case that prices are below or essentially at the equilibrium ($p_i \leq p^*$) and the case of above-equilibrium prices ($p_i > p^*$). In the former case, investments tend to be lower than

[36]The second stage of the discrete Bertrand game has the following subgame perfect equilibria: (i) if $c_i = \min\{c_{-i}\} - 1$ or $c_i = \min\{c_{-i}\}$, then $p_i^* = c_i$ or $p^* = c_i + 1$; (ii) if $c_i < \min\{c_{-i}\} - 1$, then $p_i^* = c_{-i} - 1$; (iii) if $c_i > \min\{c_{-i}\}$, then $p_i^* \geq c_i$.

[37]Note, however, that we observe merely in 12% (9%) of the two (four)-player markets successful collusion, i.e. that both players in the two-player or the two players with the lowest marginal cost in the four-player treatment set the same price above p^*.

in the latter. This confirms the interpretation that above equilibrium ("collusive") prices and high investments tend to go together.

We finally add some brief comments on the Cournot investment game. We consider the four-player game. Interestingly, when the average investments are close to the equilibrium prediction, the same is true for market outputs in the second stage.[38] More generally, there is a clear and significant relation between outputs and investments. When we regress the outputs of a firm over own investments and competitor investments, the former have a positive effect, whereas the latter have a negative effect.[39] Both of these effects are consistent with the theoretical prediction, but smaller. Intuitively, the marginal effect of higher output on profits increases when own costs are low and decreases when competitor costs are low (because low-cost competitors produce a higher output and hence market prices are lower). Conversely, the value of investing is higher when one expects to produce high outputs.

The logic of the relation between investments and outputs is therefore related to, but different from the Bertrand case. There, investments were highest for firms in situations with high prices, because optimistic firms would chose high investments and expect to get away with high prices. Now optimistic firms expect competitors to choose low investments and low outputs. Therefore, optimistic firms should choose high investments and high outputs.

6 Conclusion

This paper has analyzed the effects of more intense competition on investments in simple two-stage R&D models. In the first stage, firms whose marginal costs are identical ex-ante simultaneously invest in R&D. The investment leads to a decrease in marginal costs. In the second stage of the game, firms simultaneously choose quantities or prices in a homogeneous good market. We show that an increase in the number of firms tends to reduce investments, whereas a shift from Cournot to Bertrand increases investments. The latter observation is partly predicted by theory (for two firms) and partly the result of overinvestment in the Bertrand case.

A simple set of experiments cannot resolve the debate about the effects of competition on investment. First, there are conceptual ambiguities at the theoretical level. Even the definition of increasing competition is contentious, some insight-

[38]In the 14 cases where the average individual investment is 2, the average market output is 24.5 (as opposed to 25.6 in the continuous subgame equilibrium).

[39]The equilibrium output of firm i is $q_i = \frac{a-c}{5} + \frac{4}{5}y_i - \frac{1}{5}\sum_{j\neq i} y_j$. In an OLS regression with outputs as dependent and investments and period dummies as independent variables, the coefficients are 0.340 for y_i (significant at the 1%-level) and -0.089 for y_j (significant at the 10%-level).

ful attempts to structure the debate notwithstanding.[40] Second, even for specific notions of increasing competition in two-stage games, there are many models to investigate the issue.[41] Finally, one may worry about the external validity of the laboratory setting as a means of testing predictions about the long-term strategic decisions of managers in large firms.

However, our analysis provides a clear result that is worthy of further investigation: In some situations, there are behavioral effects that support a positive effect of competition on investment.

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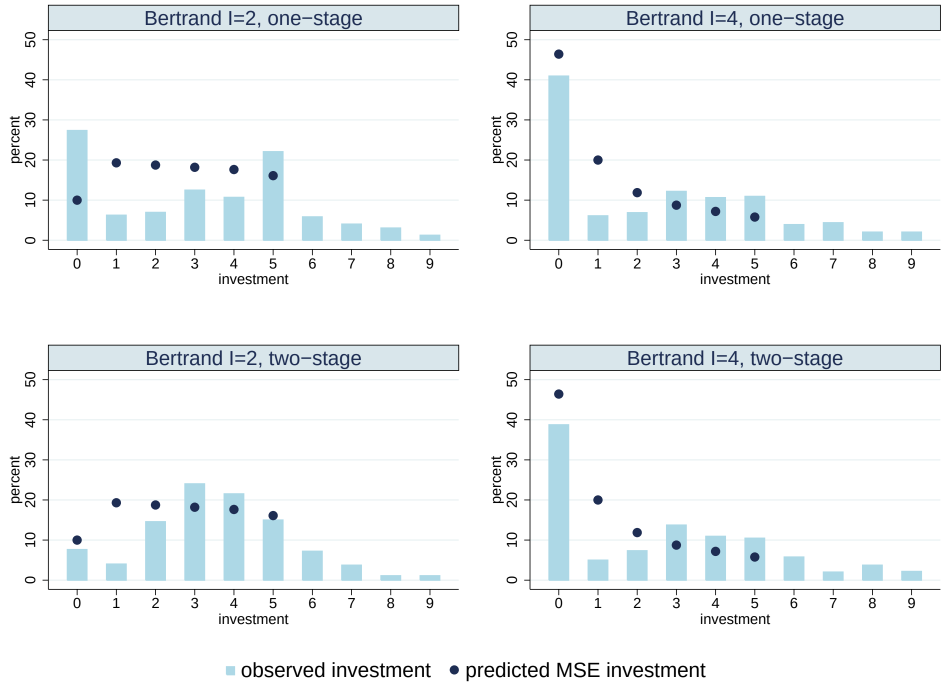
[40] See for instance Boone (2000).

[41] Vives (2008) provides a unifying discussion of two-stage games, with the extent of product differentiation as an inverse measure of competition. Schmutzler (2010) extends the discussion to other measures of competition.

Appendix

A.1 Figures

Figure 4: Observed investment levels in all Bertrand treatments and predicted MSE investment levels



A.2 Tables

Table 7: Observed and predicted investment

Cournot $I = 2$, $y_t^{i*} = 2$						
Δy_t^i	(1)		(2)		(3)	
β_0	0.514***	(0.126)	0.218	(0.135)	0.366***	(0.097)
N	720		720		1440	
Cournot $I = 4$, $y_t^{i*} = 2$						
Δy_t^i	(1)		(2)		(3)	
β_0	-0.061	(0.154)	-0.430*	(0.141)	-0.245*	(0.119)
N	640		640		1280	
Bertrand $I = 2$, $y_t^{i*} = 2.62$						
Δy_t^i	(1)		(2)		(3)	
β_0	0.477***	(0.121)	0.929***	(0.177)	0.703***	(0.118)
N	720		720		1440	
Bertrand $I = 4$, $y_t^{i*} = 1.27$						
Δy_t^i	(1)		(2)		(3)	
β_0	1.152**	(0.297)	1.286***	(0.121)	1.219***	(0.151)
N	640		640		1280	

Standard errors in parentheses are corrected for matching group clusters.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

In model (1) we use one-stage data, in model (2) two-stage, and in model (3) we pool one- and two-stage data.

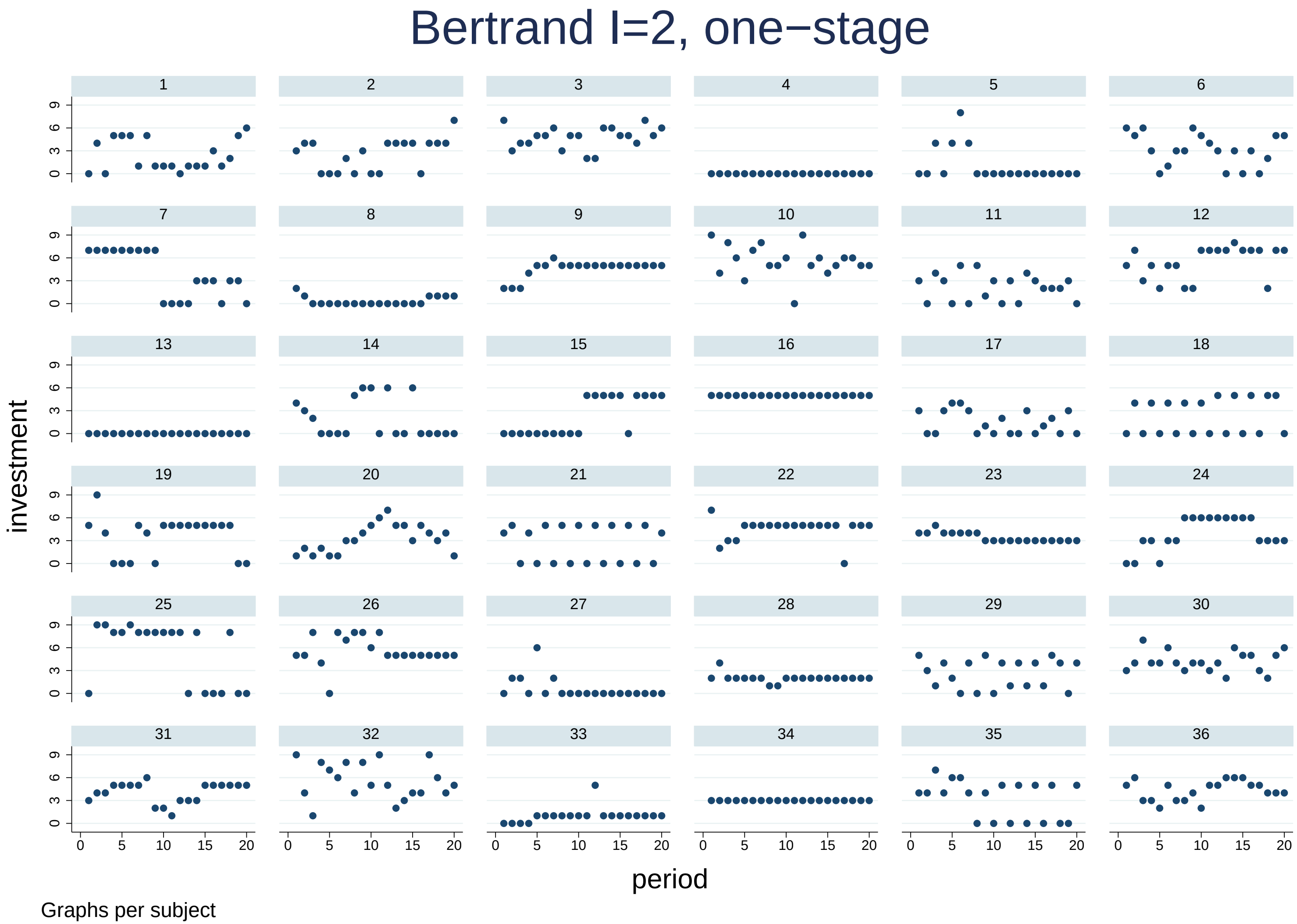


Figure 5: Individual investment path in the one-stage I2 Bertrand treatment

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Chapter 3

Patents versus Subsidies: A Laboratory Experiment

joint with Jens Großer and Nadja Trhal

1 Introduction

Patents and subsidies are widely-used policy instruments to incentivize firms to invest in R&D.[1] It was shown that sufficient R&D investment is crucial for economic growth due to its positive effect on firm profits and productivity, and thereby eventually on total welfare in the economy.[2] Empirical evidence, however, suggests that firms' private returns on R&D investment are often lower than the social returns, e.g., Bloom, Schankerman, and van Reenen (2010) estimate private returns to be about 18 percentage points lower than social returns. The reason for this inequality lies in the special properties of the good 'innovation' itself. For instance, a firm can only get a substantial profit from an innovation if the innovation is exclusive, i.e., not freely available to its competitors. In general, the amount of R&D investment will depend on the degree of appropriability of an innovation and thus on the realizable profits of an investing firm. Policy instruments are used by the government with

[1]The instruments are especially common in various industries like consumer electronics, pharmaceuticals, or automobile. In the fiscal year 2007, for instance, 184,376 patents were granted in the U.S. (39.37% of the applications) and the U.S. government funded 9.22% (24,450 out of 265,193 millions of US-$) of the industry's R&D expenditures (see Performance and Accountability Report 2008 by the United States Patent and Trademark Office and Info Brief 2008 of the National Science Foundation).

[2]For empirical studies investigating firms' R&D investment behavior and its effect on economic growth see e.g., Bernstein (1996), Cohen (1995), Cohen and Levin (1989), Jones and Williams (1998, 2000), or Steger (2005).

the intention of providing the missing investment incentives and solving or at least diminishing the problem of underinvestment. The most frequently implemented instruments are patents, subsidies, granting research joint ventures, or announcing research tournaments.[3] But, whether the policy instruments increase investment by the intended amount is anything but clear.

In this paper, we focus on the incentive effects of patents and subsidies on firms' R&D investment decisions. Furthermore, we analyze their impact on total social welfare as well as on the distribution of welfare between consumers, producers, and the government. Instead of using real-world data as it is done in empirical research, we use a controlled laboratory experiment to test for the incentive effects of each instrument. By doing so, we can keep any other possible influences fixed and are thus able to disentangle the induced effects. Further, we are able to directly compare the performance of the two instruments between each other and with a benchmark situation in which we provide no additional investment incentives. To our best knowledge this is the first study directly comparing the performance of patents and subsidies using a laboratory experiment. We find evidence that (i) subsidies and patents have a significantly positive impact on R&D investment and that (ii) the effect of both instruments on incentives to innovate is not significantly different. However, our experiment also shows that (iii) firms overinvest in all three scenarios compared to the theoretical prediction of the profit maximizing R&D investment. This gives rise to a perverse result with respect to social welfare: The level of welfare reached without providing additional investment incentives is as high as the one intended to reach by making use of policy instruments. Apart from that, we show which instrument is favored by which interest group, i.e., by consumers, producers, or the government.

There exists a vast theoretical and empirical literature also including some experimental studies analyzing the effects, usage, design, and drawbacks of the two policy instruments[4]. The impact of granting patent protection is typically analyzed in dynamic patent race models (among others see Harris and Vickers (1987)).[5] In these studies patent protection of an innovation indeed increases equilibrium R&D investment. However, by creating a the-winner-takes-all situation, patent races might systematically induce excessive spending on R&D (i.e., higher than socially op-

[3]For an overview of different aspects of R&D spending and incentive instruments refer to Scotchmer (2005).

[4]For patents please refer to e.g., Reinganum (1983), Wright (1983), or Sakakibara and Branstetter (2001); for subsidies to e.g., Spencer and Brander (1983), Romano (1989), Hinloopen (2000, 2001), or Aerts and Schmidt (2008).

[5]Among various aspects of patent laws that have been already studied in the economic literature are the optimal length and breadth of patents (e.g., Nordhaus (1969); Gilbert and Shapiro (1990); Klemperer (1990); Gallini (1992); Chang (1995)). There exist also studies on patent races focusing on the timing of investment and the different behavior of leaders and laggards see e.g., Breitmoser, Tan, and Zizzo (2010), Zizzo (2002) and Kähkönen (2005).

timal investment levels) with negative effects on welfare (see e.g., Dasgupta and Stiglitz (1980), or Loury (1979)). Early empirical studies show that 36% of R&D expenditure would not have been carried out if patent protection was not available. The degree varies between industries and is higher in industries in which imitation costs are low (Mansfield, Schwartz, and Wagner (1981) and Mansfield (1986)). A structural estimation of the patent premium, firms' expected net payoff of patent protection, is done by Arora, Ceccagnoli, and Cohen (2008) and they show that an increase of the patent premium rises firms' R&D spending. The more effective patent protection is, the higher is the investment incentive and the larger is the rise of R&D expenditure. Experimental studies on a one-stage stochastic R&D process by Isaac and Reynolds (1986, 1988) show that subjects invest more under full[6] than under partial appropriability and that the R&D investment exceeds the socially optimal amount under full appropriability. Subsidies as another policy instrument are used to stimulate investment and to decrease the risk of firms investing in R&D since the sunk costs in case of failure are reduced. Subsidies should encourage firms either to invest more or to overcome a threshold of investing in R&D. Theoretical work (see e.g., Hinloopen (2001)) concerning the impact of subsidies indicates that investment levels as well as welfare are increased, but that profits are decreased. An experimental study on the effects of subsidies and appropriability on stochastic R&D investment by Davis, Quirmbach, and Swenson (1995) also proves that R&D investment is increased significantly by a subsidy.[7]

Apart from studies investigating the impact of a single incentive instrument, there exists a literature addressing the question of the optimal policy mix. However, the answer to that question is ambiguous. Romano (1991) shows that it is almost never optimal to offer patent protection and subsidization at the same time, but Li (2001) finds in the context of a growth model that it is always optimal to subsidize as long as the government can set the patent breadth. An interesting insight is provided by Schankerman (1998) who estimates the value of patent protection in terms of the degree of subsidization which is needed to reach the same amount of R&D investment. He estimates the "equivalent subsidy rate" to be about 25%. Arora, Ceccagnoli, and Cohen (2008) do the same estimation and estimate a rate of 33%. Summarizing, the existing literature provides evidence that patents as well as subsidies have a substantial impact on rising R&D investment, but does not show which of the two instruments is better in stimulating investment and which is more favorable from the consumers' or producers' point of view.

[6] Full appropriability of an innovation means that the innovating firm gains the complete profits induced by the innovation, i.e., monopoly profits. Therefore full appropriability corresponds to patent protection.

[7] Other experimental studies on subsidizing R&D like those by Buckley, Mestelman, and Shehata (2003) and Cooper and Selto (1991) rather focus on the effect of different designs of the subsidy in form of tax benefits and R&D project funding (see Giebe, Grebe, and Wolfstetter (2006)).

In contrast to the existing experimental literature we directly compare the effect of the two instruments using the framework of a two-stage game[8] in which at a first stage subjects are asked to invest in an uncertain R&D project followed by a market stage with Bertrand price competition.[9] Note that by additionally implementing a market stage (second stage of the game), a firm's private returns from R&D are determined endogenously in the Bertrand competition stage (by price setting) and are not exogenously given. Following Dufwenberg and Gneezy (2000) who show that three firms are enough to let prices converge to equilibrium prices in Bertrand games, a market is assumed to consist of three competing firms.
We run three treatments: one for each policy instrument and - as a benchmark - one without any incentive instruments. In the first two we provide either patent protection or subsidize investments, i.e., lower the firms' investment costs. In order to make patent protection and subsidizing perfectly comparable, the experimental parameters for both incentive instruments are chosen in a way that in equilibrium the profit maximizing investment for firms and thus the social welfare evolving from both are equal. Specifically, in our model the patent protects the innovation during the whole market duration and the subsidy is chosen in such a way that the investment induced will equal the investment under patent protection in equilibrium.

The remaining part of the paper is structured as follows. Section 2 presents the theoretical model, which is followed by the experimental design and proceedings in Section 3. Section 4 encloses the experimental results and with a discussion, in Section 5, we conclude.

2 The Model

Consider the following two-stage game with i=1,...,n risk-neutral firms. Table 1 shows the structure of the game: At the first stage ('R&D investment stage'), each firm starts out with identically high marginal costs $c_i^H = c^H$, $\forall i$, and independently decides on the amount it invests in R&D, $r_i \in [0,1)$, to gain low marginal costs, $c_i^L = c^L > 0$, $\forall i$, with $0 \leq c^L < c^H$.[10]

[8]Two-stage games are used as well to experimentally investigate investment behavior in R&D by e.g., Jullien and Ruffieux (2001), Suetens (2008), Isaac and Reynolds (1992), Sacco and Schmutzler (2011), and Chapter 2. However, all studies mentioned do not make a comparison of the investment incentive induced by different policy instruments, but, e.g., analyze the effect of changes in the degree of competition on the investment incentive.

[9]A Bertrand market is chosen for simplification in the experiment and to follow the patent race literature which often uses a the-winner-takes-all assumption, for a general model see Harris and Vickers (1987). In our setting only an exclusive innovating firm can reap all profits at the market stage, the other firms receive nothing.

[10]Each firm chooses privately and simultaneously an R&D investment level.

Table 1: Structure of the two-stage game

1st stage	n firms invest each $r_i \in [0,1]$ and receive with probability $F(r_i)$ low marginal costs c^L; investment costs are $(1-\sigma)r_i$	single investment decision
2nd stage	firms have either low (c^L) or high marginal costs (c^H) and set prices $p_{i,t}$ in each period:	1,...,T Bertrand market periods
	low marginal costs c^L cannot be imitated	1st market period
	low marginal costs c^L are protected from imitation by a patent	$\theta = 0, 1, ..., T-1$ market period
	low marginal costs c^L can be imitated	$T-\theta-1$ market periods

Firm i's probability of successful R&D is given by a continuous cumulative distribution, $F(r_i)$, with density $f(r_i)$, and we assume $F(0) = 0$, $F(1) = 1$, and that $F(\cdot)$ is monotone and concave (i.e., $f(r_i) > 0$ and $f'(r_i) < 0$ for $r_i \in [0,1]$, respectively). In words, we assume constant marginal costs and diminishing returns from R&D investment.[11] At the second stage ('market stage'), t=1,...,T consecutive Bertrand market periods take place in each of which firms simultaneously set their prices, $p_{i,t}$, at which they sell a homogeneous good.[12] Consumers only buy at the lowest market price, $p_t^{\min}$, and we assume the same (normalized) price-inelastic market demand in each period, Q=Q_t=1, $\forall t$.[13] In the first Bertrand market period, each firm's marginal costs, c^H or c^L, only depend on its own success in the R&D investment stage.[14] We assume, without loss of generality, that high cost firms can then imitate the production technology of low cost firms at no cost and also produce at c^L beginning in the second market period. Thus, in absence of any imitation-prohibiting policy, a firm's marginal costs in the second and all subsequent market periods depend not only on its own success but also on whether or not at least one firm has successfully innovated in the first period.

We examine two common government R&D policies that influence the firms' incentives to invest in R&D: *subsidies* and *patents*. Subsidies target at the cost side of each firm's expected profit from R&D by covering a proportion $\sigma \in [0,1]$ of its

[11] Although it is debated whether R&D investments exhibit diminishing returns in the empirical literature, we follow the theoretical papers in the tradition of d'Aspremont and Jacquemin (1988). For comments on that matter please refer, e.g., to Kamien and Schwartz (1975), Griliches (1990), and Nadiri (1993). We also refrain from modeling fix costs, FC, as we do not analyze any decisions to enter the market.

[12] For simplicity, we assume that firms only produce when they can sell.

[13] An implication of assuming price-inelastic demand is that the innovation will be automatically non-drastic since the monopoly price before and after the innovation (which equals the prohibitive price $\bar{p}$) is assumed to be higher than c^H.

[14] We assume that there are no technological spillovers at the investment stage: each firm i's chances of a successful innovation depend only on its own investment r_i, not on a rival's investment r_j.

R&D costs (i.e., each firm i pays $(1-\sigma)r_i$ and government pays σr_i). Patents, in contrast, target at the revenue side of each firm's expected profit by protecting innovating firms beyond the first period. More precisely, government prohibits high cost firms to apply imitated production technologies for other *θ=0,1,...,T-1* market periods after the first market period. Note that each successfully innovating firm obtains patent protection in our model, i.e., more than one firm in a market might be provided with a patent. Thus, patent protection does not automatically create a monopoly. One might argue that this is no 'pure' patent protection (in the sense of 'the winner takes all'). However, it is realistic to assume that firms might invest in different technology innovations yielding a cost reduction and that these different technologies are protected. Finally, we assume that the game structure and parameters as well as the R&D success of each firm and the government R&D policy (hence the marginal cost of each firm in each market period) are common knowledge. In the next subsections we analyze our two-stage game. Due to backward induction we start the analysis with the second stage of the game followed by the first stage.

2.1 Market Stage

Depending on the government's R&D policy and the firms' R&D successes at the first stage, we distinguish between different compositions of marginal costs in each Bertrand market which lead to different market prices (for simplicity, we refrain from indexing R&D policies and market periods). We assume that among the firms which offer the lowest price those with the lowest marginal costs share the demand equally.

(1) The market price equals the lowest marginal costs in the market and is thus either $p^* = c^H$or $p^* = c^L$. $p^* = c^H$is the market price if *no firm has low marginal costs* and $p^* = c^L$is the market price if *at least two firms have low marginal costs.* Hence, the market profits for all firms are $\pi^* = 0$.

(2) A market price higher than the lowest marginal costs is set if merely *one firm has low marginal costs.* This firm sets a price as high as the competitors' marginal costs, i.e., the market price equals high marginal costs, $p^* = c^H$. Thus, the firm with low marginal costs receives positive market profits $\pi_i^* = p_i^* - c^L \equiv c^H - c^L > 0$ while the competitors receive zero market profits $\pi_{-i}^* = 0$, $\forall -i \neq i$.

For a more detailed derivation of the market prices, see, for instance, Motta (2004).

Note that (2) may apply to the first market period and all periods that are patent protected by government, but in all other cases either no firm or all firms have low marginal costs. Moreover, note that market prices as well as Nash equilibrium profits are unique for each cost structure (though there are infinitely many Nash equilibrium price constellations) and that the only equilibrium situation in which a firm makes strictly positive market profits is in case it is the only low cost firm.

2.2 R&D Investment Stage

In this subsection we analyze the investment decision at the first stage. In the following we concentrate on the case that all firms' R&D investments are symmetric (i.e., $r_i \equiv r$, $\forall i$) as a benchmark case. Note that there might also exist asymmetric equilibria. We will discuss the equilibrium selection in more detail in Sections 3.1 and 4.1. At the R&D investment stage, each firm knows the government's R&D policy and anticipates all possible Nash equilibrium profits at the market stage.

Proposition 2.1. *The symmetric Nash equilibrium level of R&D investment, $r^*(n, \Delta c, \theta, \sigma) \in [0,1]$, is characterized by the necessary and sufficient condition*

$$f(r^*)\,[1-F(r^*)]^{n-1}\,(1+\theta)\Delta c = 1-\sigma. \qquad (1)$$

The optimal investment level in R&D r^* is increasing in the mark-up from being the only low cost firm $\Delta c = p - c^L = c^H - c^L$, the number of patent-protected periods θ, and the subsidized proportion of the firms' R&D investment costs σ. However, r^* is decreasing in the number of firms n; and it is independent of the number of market periods T.

The proof is given in Appendix A.1.

Proposition 2.1 implies that both policy instruments provide incentives for the firms to increase their investment levels in R&D. Moreover, as a firm can only achieve positive profits under Bertrand competition if it is the sole innovating firm in its market, the incentive to invest in R&D increases the higher this mark-up is. In our model investment levels decrease with tougher competition (i.e., an increase in n), because it becomes less probable that a firm is the sole innovator the more competitors are in the market. Note that there is huge literature studying the impact of market structure on investment behavior providing mixed results (for studies on the different effects of competition on investment see e.g., Boone (2000), Schmutzler (2010), Vives (2008), or Chapter 2 for an experimental investigation).[15] The equilibrium value of r is independent of the number of market periods T, but dependent of the number of patent-protected market periods θ. Since the number of market periods in which a single low cost firm can make positive profits is in

[15]Cohen and Levin (1989, p. 1075) already stated that "[e]conomists have offered an array of theoretical arguments yielding ambiguous predictions about the effects of market structure on innovation."

our model reduced to the first period and in the patent case determined by the additional number of patent-protected market periods θ.

2.3 Distributional Effects

In this subsection we distinguish the welfare shares (or rents) of the different interest groups (firms, consumers and government) in order to analyze the effects of an increase in the subsidized proportion and in the number of patent-protected periods, respectively. Thereby, we do not focus on absolute changes of the rents, but rather on rent shifting between different interest groups. Given equilibrium behavior of the firms (i.e., the symmetric Nash equilibrium investment level of $r_i^*(\sigma, \theta) = r^*(\sigma, \theta)$, $\forall i$), we investigate the impact of each policy instrument on added rents.[16] Proposition 2.2 indicates that different policy instruments have different distributional consequences.

Proposition 2.2. *An increase in the subsidized proportion of the firms' R&D investment costs induces a transfer from government to firms as well as expected rent shifting between consumers and firms; an increase in the number of patent-protected market periods induces as well expected rent shifting between consumers and firms.*

The proof is given in Appendix A.1.

However, note that the sign of the shifted transfers between consumers and producers depends on the concrete parameterization. Precise predictions for our experimental setup are derived in the next section in order to analyze which group benefits from an introduction of subsidies and patents, respectively.

3 Experimental Predictions and Design

In the first section, we parameterize the model to derive the hypotheses for the experiment and in the second section, we describe the experimental design.

3.1 Experimental Set-Up: Equilibrium Predictions and Hypotheses

Table 2 summarizes the treatment parameters of our experimental set-up.[17] Specifically, we use the continuous cumulative probability distribution of R&D success

[16] Note that we use added rents, i.e., we consider the change of actual total rents in case firms invest in R&D in comparison to the situation in which no firm invests in R&D.

[17] In the following the standard case with no instrument is called *NO*, the subsidy case is called *SUB* and the patent case *PAT*.

$F(r_i) = \frac{1}{10} r_i^{0.5}$, $\forall r_i \in \{0, 99\}$, with density $f(r_i) = \frac{1}{20} r_i^{-0.5}$ and $f'(r_i) = -\frac{1}{40} r_i^{-1.5}$, and $n = 3$, $c^H = 500$, $c^L = 100$ and $T = 2$. As the market stage consists only of two market periods and a cost reduction can only be imitated in the second period, we set the patent-protected rounds equal to $\theta = 1$ ($\theta = T - 1$), i.e., the patent protects the innovation during the whole market duration T. The subsidy proportion $\sigma = \frac{1}{2}$ is chosen such that the two policy instruments (patents and subsidies) induce equal symmetric Nash equilibrium investment levels.

Table 2: Treatment parameters

Treatment	Investment costs	Cost structure 1st market period	Cost structure 2nd market period	Number of independent observations (sessions)
NO	r_i	$c_{i,1} \in \{c^L, c^H\}$	$c_{i,2} = \min[c_{1,1}, c_{2,1}, c_{3,1}]$	5(1)
SUB	$0.5r_i$	$c_{i,1} \in \{c^L, c^H\}$	$c_{i,2} = \min[c_{1,1}, c_{2,1}, c_{3,1}]$	5(1)
PAT	r_i	$c_{i,1} \in \{c^L, c^H\}$	$c_{i,2} = c_{i,1}$	5(1)

The cost structure is given by $c_{i,t}$, where i denotes the firm and t the market period.

The continuous equilibrium predictions which will be used as a benchmark for our data analysis are given in Table 3 for our concrete parameters.[18] The equilibrium R&D investments lead to the same added welfare in *SUB* and *PAT* which is higher than in *NO*.[19] Comparing the effect of an introduction of each R&D policy instrument with the situation without policy instruments Table 3 indicates that an introduction of subsidies decreases the firms' expected added profits and government rent, and increases expected added consumer rent. The introduction of patent protection increases the firms' expected profits and decreases expected consumer rent. Thus, in our concrete experimental set-up the introduction of a subsidy partly shifts rents from firms to consumers and the introduction of a patent partly shifts rents from consumers to firms.

The symmetric Nash equilibrium investment level and the corresponding implications for welfare shares yield testable predictions about the incentives to invest in R&D. Let us summarize our main experimental hypothesis which will be tested in Section 4:

Hypothesis 3.1. *Investment levels increase if a policy instrument (SUB, PAT) is introduced.*

Hypothesis 3.2. *Welfare increases if a policy instrument is introduced.*

[18] Derivations of equilibrium investment levels are given in Mathematical Appendix A.1.2. Note that the presented investment levels are the symmetric Nash equilibria. In *SUB* and in *PAT* in addition there exist three asymmetric Nash equilibria given by (56.25, 56.25, 6.25).

[19] The formula for added welfare as well as the individual welfare shares (added consumer, producer and government rent) are given in Mathematical Appendices A.1.1 and A.1.2.

Table 3: Experimental predictions

Treatment	Nash eq. investment	Added welfare	Added consumer rent	Added producer rent	Added government rent
NO	25.00	625.00	550.00	75.00	0.00
SUB	37.16	640.92	640.90	55.76	-55.74
PAT	37.16	640.92	529.40	111.51	0.00

For the derivation of welfare shares we use the continuous symmetric Nash equilibrium investment levels given in Table 4 as well as $T = 2$, $\theta = 1$, $\sigma = 0.5$, and $\Delta c = 400$.

Hypothesis 3.3. *Consumers prefer SUB to NO to PAT, firms prefer PAT to NO to SUB*[20].

3.2 Experimental Design and Procedures

The computerized[21] experiment was conducted at the Cologne Laboratory for Economic Research in December 2005. We ran 3 sessions (baseline (*NO*), subsidy (*SUB*) and patent (*PAT*) treatment) each with 30 subjects.[22] Each session lasted about 1.45 hours (cf. Appendix A.5 for the instructions). Earnings in the experiment were expressed in points. At the end of a session, point earnings were transferred to cash at an exchange rate of 300 points = 1 €. Subjects earned on average 14.95 € including a 2.50 € show-up fee (average earnings amount to: 16.53 € in Session 1 (*PAT*), 13.84 € in Session 2 (*SUB*) and 14.48 € in Session 3 (*NO*).

Each session consists of 30 decision rounds. At the beginning of the experiment, subjects are randomly divided into 5 matching groups of 6 subjects each. At the beginning of each round 3 subjects (i.e., 'firm' 1, 2, and 3, respectively) are randomly matched.[23] Though subjects know they are randomly re-matched in each round, they are not informed that this happens within matching groups. Hence, each session provides us with five independent observations.

Each round of the 30 rounds is divided into two phases. Phase 1 corresponds to the investment stage and phase 2 to the market stage with two consecutive market periods T=2 (labeled phase 2A and 2B, respectively). In the *NO* treatment, each subject receives an endowment of B=100 points at the beginning of each round. In

[20] Note, firms prefer *NO* to *SUB* because the firm's expected profit is higher in *NO* than in *SUB*. The reasoning is that the effect of the higher probability of being the alone innovating firm due to the lower investment in *NO* overweighs the effect of the lower investment costs in *SUB*.

[21] The experimental software was programmed using z-Tree (Fischbacher 2007).

[22] Subjects were recruited using ORSEE (Greiner 2004). The vast majority (96%) of subjects were undergraduate students from the University of Cologne, mostly belonging to the faculty of management, economics and social sciences.

[23] We use strangers matching to avoid cooperation in a repeated game and to retain the one-shot character. Price competition experiments show that three firms are sufficient to ensure near Bertrand-equilibrium prices (see Dufwenberg and Gneezy (2000)).

phase 1, each subject has to make an investment decision by choosing an integer of $r_i \in \{0, 1, ..., 99\}$ points, which is subtracted from his endowment B. Moreover, each subject starts with high production costs of $c_i^H = 500$ points. Depending on the investment decision r_i and chance, represented by the realization of the cumulative probability function $F(r_i) = 0.1(r_i)^{0.5}$,[24] an innovation may occur which decreases production costs to a lower level of $c_i^L = 100$ points. [25] At the beginning of phase 2, each subject is informed about whether or not he successfully innovates, i.e., achieves lower production costs, and also about the innovation success of the other two subjects in his group (but not about their investment decisions). Thereafter, the first Bertrand market (phase 2A) starts, in which each subject has to submit a price $p_{i,1} \in \{c_{i,1}, c_{i,1} + 1, ..., 1000\}$ between his own production costs $c_{i,1} \in \left\{c_{i,1}^L, c_{i,1}^H\right\}$ and a prohibitive price of 1000 points. The $n_1 \in \{1, 2, 3\}$ subjects with the lowest submitted price in the market can sell their goods[26] each earning $\pi_{i,1} = \frac{1}{n_1}(p_{i,1} - c_{i,1})$ points in the first market, whereas subjects with higher prices earn nothing (zero points). Each subject is informed about the lowest price and his own profit in the first market, but no other information is given. In the second Bertrand market (phase 2B), due to costless imitation opportunities, each subject starts with the lowest production cost among the firms in the first market $c_{i,2} = \min\left[c_{1,1}, c_{2,1}, c_{3,1}\right], \forall i$. The procedure in the second market is exactly the same as in the first market: those subjects with the lowest price (n_2) obtain profits of $\pi_{i,2} = \frac{1}{n_2}(p_{i,2} - c_{i,2})$ points and those with higher prices zero-profits. At the end of each round, each subject i is informed about his round profits, which are given by $\pi_i = \pi_{i,1} + \pi_{i,2} - r_i + B$, and his total profits so far.

In the *PAT* treatment, exactly the same procedure as in *NO* is applied, with the only difference that imitation in the second Bertrand market is prohibited ($\theta = 1$): Each subject's production costs in the second market are equal to his own costs in the first market $c_{i,1} = c_{i,2}, \forall i$. Finally, the *SUB* treatment differs in only one aspect from *NO*: As half of the investment costs are subsidized ($\sigma = \frac{1}{2}$), a firm's investment costs are reduced from r_i to $0.5r_i$ (compare also Table 2).

[24]To simplify matters ri is divided by hundred, since this allows subjects to choose integer numbers between 0 and 99 in the experiment instead of decimals. Note that by excluding an investment level of 100 cost reduction remains stochastic even for the maximum investment.

[25]In the experiment subjects are given a table which specifies the investment costs and the probability of a cost reduction (i.e., a successful innovation) for each possible investment level. Given a subject's investment decision, the computer program randomly determines based on the corresponding cumulative probability function $F(r_i)$ whether or not the subject 'innovates', i.e., achieves lower production costs (for more details of these procedures and the given table see the instructions in Appendix A.5).

[26]In order to make the design as simple as possible for the subjects, those subjects with the lowest price share the demand equally. Thus, we relax the assumption of our model that among those firms which offer the lowest price only those with the lowest marginal costs share the demand. Note that this implies that the achievable mark-up of a sole innovator decreases to $\Delta c = 399$, since its equilibrium price decreases to 499.

4 Experimental Results

The presentation and analysis of our experimental data are organized as follows. We start by examining R&D investment levels (4.1) including investment dynamics over time and individual behavior. Thereafter, we investigate firms' price setting and resulting profits in the Bertrand markets (4.2). Finally, we analyze the effects of subsidies and patents on social welfare as well as on welfare for special interest groups, i.e., firms, consumers and government (4.3). In case average results are presented, the term average refers to mean value over rounds in the subsequent analyses. Laboratory findings and their comparisons with the respective Nash predictions are summarized as *experimental results* (ER) at the end of each section.

4.1 R&D Investments

Table 4 shows the average R&D investment for each treatment and the predicted symmetric Nash equilibrium for continuous investment levels.[27] At first sight, there are two remarkable aspects. First, the observed investment level is higher using a policy instrument like subsidy or patent in comparison with our baseline treatment with no R&D policy: Subsidies and patents increase firms' R&D investment levels by 35.79% and 45.62%, respectively. This indicates that both instruments serve the purpose of rising investment levels supporting Hypothesis 3.1.[28] Using matching group averages as independent observations a Kruskal-Wallis test reveals that we can reject the hypothesis that the investment levels of all treatments are drawn from the same population.[29] Pair wise Mann-Whitney-U tests reveal significant differences between *NO* and *SUB* as well as between *NO* and *PAT* whereas *SUB* and *PAT* investment levels do not differ significantly.[30] Second, the observed average R&D investment in the experiment is always higher than the predicted Nash equilibrium for each treatment. R&D investments are about 37.92% (26.00%; 35.12%) higher than theoretically predicted by the symmetric Nash equilibrium in *NO* (*SUB*, *PAT*). We will later discuss possible explanations for this overinvestment.

[27]We take the continuous symmetric Nash equilibrium as a benchmark. Note that we get multiple equilibria in case of discrete investment levels (all equilibria are given in Table 12 in Appendix A.4). However, continuous and discrete equilibria do not differ (much) as long as we concentrate on symmetric equilibria (discrete symmetric equilibria are 25, 37, 37 in *NO*, *SUB*, *PAT*).

[28]However, note that the theoretical increase in investment levels is higher: Investment levels are predicted to be 48.64% higher in *SUB* (and *PAT* respectively) than in *NO*.

[29]In the following nonparametric tests we always use matching groups as independent observations.

[30]One-tailed Mann-Whitney-U tests reject the null hypothesis of no differences in average investments in favor of higher investment levels in *SUB* and *PAT* than in *NO* (p=0.016) respectively (p=0.004), but cannot reject the null hypothesis for the comparison of *SUB* and *PAT* (p=0.21).

Table 4: Average observed and predicted R&D

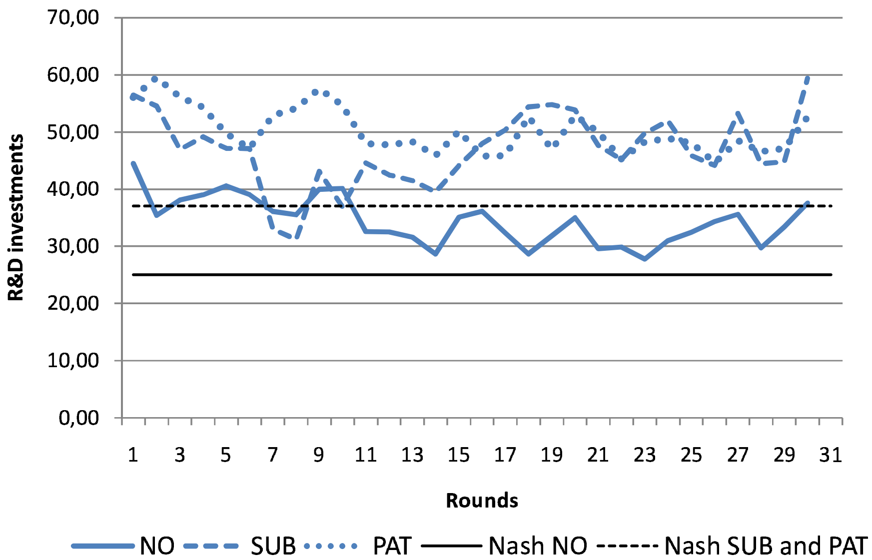
Investment levels	*NO*	*SUB*	*PAT*
Observed	34.48	46.82	50.21
	(23.67)	(32.13)	(35.61)
Predicted	25.00	37.16	37.16

Standard deviations are given in parentheses.

4.1.1 Time Path of Investment

Figure 1 depicts observed and predicted average R&D investment levels per round. These levels are higher than predicted by the symmetric Nash equilibrium in all rounds in each treatment (with only three exceptions in *SUB*). Considering investment behavior over time, average R&D investment levels decrease from the first to the second half of 30 rounds in *NO* and *PAT* (36.59 vs. 32.36 and 52.14 vs. 48.28, respectively), but increase in *SUB* (43.81 vs. 49.82). However, Wilcoxon Signed Rank tests yield significant results only for the decrease in investments in *NO* at the 5% significance level.

Figure 1: Observed and predicted R&D investments over rounds



To examine the dynamics of R&D investment decisions at the individual level, we use a simple ordinary least squares regression (Table 5). Due to dependency of the observations within matching groups we calculate clustered standard errors. As explanatory variables we consider treatment dummies and dummies for firm *i*'s success in reducing its cost in the previous round (i.e., lagged variables) as well as round dummies. The treatment dummies (*NO*, *SUB*, *PAT*) are used to generate interaction variables with the explanatory variables. In model (1) in Table 5 we consider dummies for a cost reduction due to successful innovation of a firm in the previous round CR_{t-1} (CR=1 for successful innovation, CR=0 for no innovation), where t denotes the round. Round dummies given for the first half of rounds (round 1-15) and the second half of rounds (round 16-30) as the base category are considered additionally in model (3). Moreover, in the estimated model (2) in Table 5 cost reduction dummies *CR* are subdivided into the cases that only firm i successfully reduced its costs ($CR1_{t-1}$), that firm i and one other firm j reduced their costs ($CR2_{t-1}$), and that all three firms reduced their costs in the previous round ($CR3_{t-1}$). Note that in all these categories at least firm i successfully innovates. The reference category for the three cost reduction dummies ($CR1_{t-1}$, $CR2_{t-1,}CR3_{t-1}$) is the situation that firm i did not have low costs in the previous round independent of the other firms' cost levels ($CR0_{t-1}$).

Model (1) in Table 5 shows that a successful innovation of firm i in the previous round has a positive and highly significant influence on its current investment level compared to the reference category 'no success' (CR=0). Moreover, the coefficients of all single cost reduction dummies in model (2) have a positive sign and are significantly different from zero as well: Independent of the treatment a firm i invests significantly more in the current round if at least this firm i successfully innovated in the previous round compared to the benchmark case that firm i had no success. Note that the investment level also increases if one or even both other firms in the market were also successful in cost reduction in the previous round. Note as well that being the exclusive innovator increases investment levels strongest (compare Table 13 in Appendix A.4, where we drop *CR1* as the base category; the coefficients for all other cost reduction dummies are negative compared with *CR1*). In line with the results from above we observe a round effect in *NO*: We find that investment levels in *NO* are significantly higher being in the first half of rounds (first round excluded) compared to the last half of rounds, whereas investment levels are significantly lower in the first half of rounds in *SUB* and are not significantly influenced by round in *PAT*.

The OLS regression measures the effects of the tested parameters in each treatment (i.e., whether a parameter has an influence on a firm's investment level for each treatment separately). For a comparison of effects between treatments (i.e., whether a parameter has a stronger influence in one treatment than in the other) see OLS regression results given in Table 14 in Appendix A.4. As the reference treatment we drop the treatment dummy '*SUB*'. Table 14 clearly indicates that the positive effect of firm i's successful innovation (compared to no success) on investment levels is significantly stronger in *PAT* than in *SUB* and significantly weaker in *NO* than in *SUB* (see models (1) and (3)). Moreover, the positive effect of a successful cost reduction on the investment level if firm i is the exclusive innovator or if firm i and one other firm successfully innovate is as well in *PAT* significantly higher and in *NO* significantly lower than in *SUB* (see model (2)).

Table 5: OLS regression results

Investment	Model (1)		Model (2)		Model (3)	
NO	28.262***	(2.604)	28.262***	(2.607)	26.669***	(2.347)
SUB	31.783***	(2.086)	31.783***	(2.088)	34.840***	(1.626)
PAT	27.902***	(3.671)	27.902***	(3.675)	27.329***	(3.663)
$CR_{t-1} \times NO$	11.178***	(2.226)			11.094***	(2.204)
$CR_{t-1} \times SUB$	23.341***	(3.096)			23.088***	(2.983)
$CR_{t-1} \times PAT$	37.486***	(3.884)			37.404***	(3.906)
$CR1_{t-1} \times NO$			15.823***	(2.870)		
$CR1_{t-1} \times SUB$			25.626***	(1.862)		
$CR1_{t-1} \times PAT$			46.842***	(4.337)		
$CR2_{t-1} \times NO$			11.950***	(2.581)		
$CR2_{t-1} \times SUB$			22.455***	(3.652)		
$CR2_{t-1} \times PAT$			38.120***	(2.896)		
$CR3_{t-1} \times NO$			6.231**	(2.769)		
$CR3_{t-1} \times SUB$			23.792***	(3.160)		
$CR3_{t-1} \times PAT$			31.356***	(4.070)		
round1_15$\times NO$					3.389**	(1.511)
round1_15$\times SUB$					-6.004***	(1.917)
round1_15$\times PAT$					1.286	(1.838)
R^2	0.211		0.218		0.215	
N	2610		2610		2610	
No. of clusters	15		15		15	

Standard errors are given in parentheses and are corrected for matching group clusters. As we drop the constant in the estimated models, the reported R^2 is taken from the (analogous) models as presented in Table 14 in Appendix A.4. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

4.1.2 Individual Investment Decisions

In the previous sections we focused on symmetric Nash equilibrium R&D investment strategies, which specifically imply that each firm always chooses a discrete investment level of 25 in *NO* and 37 in *SUB* and *PAT*. However, the actual investment levels are very diverse: Figure 2 specifies the frequencies of the chosen investment levels for each treatment.[31] Obviously, in the baseline treatment without policy instruments the predominant investment level is consistent with the symmetric Nash

[31] Individual investment behavior over rounds is given in Figures 7 to 9 in Appendix A.3. A small fraction of subjects sticks to a certain investment level (or adjusts the investment level only slightly over rounds). Investment levels remaining constant over rounds are most frequently observed in the *PAT* treatment.

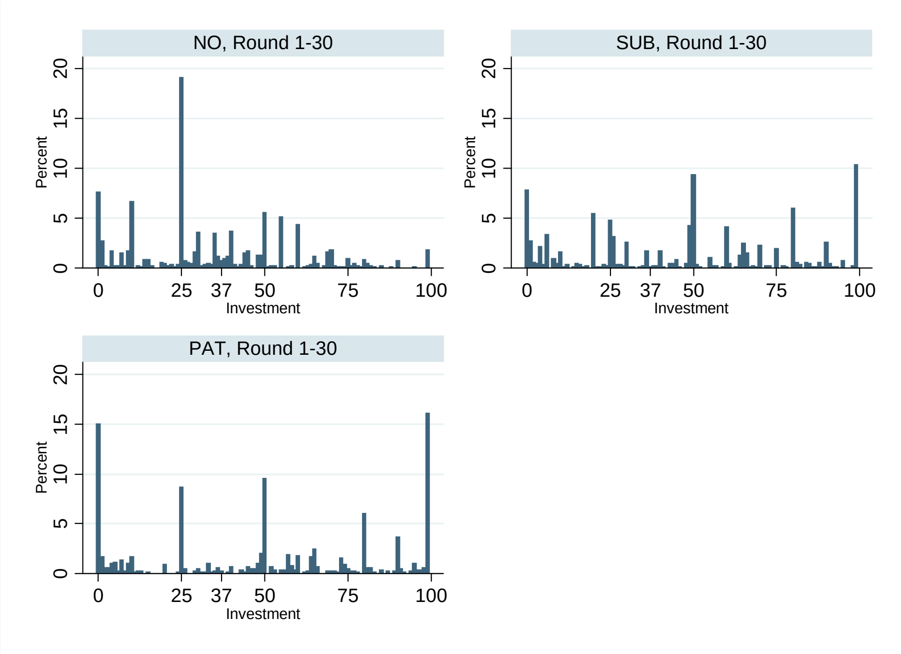
equilibrium investment level of 25 (this level is chosen in 19.11% of cases). Yet keeping the endowment and investing zero is the second most chosen behavior in this treatment. On the contrary, in the two treatments with policy instruments the Nash equilibrium of 37 is almost never chosen (in less than 1% of the cases). In the *PAT* treatment the most frequently chosen investment levels are zero (15%) and the maximum of 99 (16.11%). This behavior obeys kind of an 'all-or-none law': a subject either invests his complete endowment trying to achieve low costs (and thus a possible competitive advantage in the two market periods) or a subject decides on retaining his endowment and not trying at all to reduce his costs for the market stage. A smaller percentage of investments of 9.56% is set equal to the intermediate level of 50. In the *SUB* treatment the most chosen investment levels 0, 50 and 99 are more uniformly distributed (7.78%; 9.33%; 10.33%). Investing 99 points is the most frequently chosen strategy in both treatments with policy instruments,[32] whereas investing the maximum amount plays nearly no role in the baseline treatment. To examine these observed frequencies further, we consider asymmetric equilibria in the following. Table 6 summarizes discrete symmetric and asymmetric Nash equilibrium R&D investment levels for our experimental parameters. Note that the discrete parameterization gives raise to asymmetric equilibria. In the continuous case there exists only a unique symmetric equilibrium investment level in *NO*, and a symmetric and three asymmetric equilibria in *SUB* and *PAT* (compare Footnote 16).

To understand the frequencies shown in Figure 2, it might be helpful to consider asymmetric Nash equilibria (see Table 6). In all treatments there exist three asymmetric Nash equilibria in which two firms choose 0 and one firm chooses 99. This is consistent with the observed investment levels of 0 and 99. However, note that the predicted asymmetric equilibria of (0, 0, 99) fail to explain (i) why 99 is chosen even more often than the minimum level of zero in *SUB* and *PAT*, and (ii) why 0 and 99 are less frequently chosen in *NO* than in *SUB* and *PAT*. The first observation might hint at a possible coordination failure. The asymmetric equilibria add a substantial coordination problem to the subjects' decision task.[33] The second observation that 0 and 99 are less frequently chosen in *NO* than in *SUB* and *PAT* may be explained by additional asymmetric investment levels which exclusively occur in *NO*: In *NO* the number of discrete asymmetric Nash equilibria is highest (in *SUB* and *PAT* there exist – besides the symmetric equilibrium – only the asymmetric equilibria

[32]The accumulation of the maximum investment level in *SUB* and *PAT* might be a further indication that the introduction of either policy instrument provides stronger incentives to invest in R&D.

[33]However, there seems to be evidence that at least some subjects are aware of this coordination problem, because we observe subjects 'jumping' from very low investment levels to very high investment levels and vice versa especially in the *SUB* treatment (cf. Figures 7 to 9 in Appendix A.3). In general, investments are strategic substitutes since a subject has an incentive to decrease his own investment if a rival increases his investment and vice versa (see comparative statics in Mathematical Appendix A.1.2).

Figure 2: Investment frequencies



in which one firm invests all and the other two firms invest nothing (0,0,99)). In *NO* there are in addition asymmetric Nash equilibria consisting of R&D investment levels from the interval [20, 21,..., 30]. Note that although in *NO* the number of discrete asymmetric Nash equilibria is highest, *NO* is nevertheless the treatment in which behavior is most consistent with the symmetric Nash equilibrium. This might be due to the fact that the additional asymmetric investment levels are oscillating around the symmetric equilibrium investment level of 25. Hence, it seems that asymmetric Nash equilibria can contribute to explain some of our data.[34]

We also examine the dynamics of investment behavior in order to analyze whether there is a convergence to equilibrium levels over rounds. Therefore we consider investment behavior of the first round as well as investment behavior of the first third, second third and last third of rounds separately (Figures 3 – 5). Strikingly, investment levels of 25 (which is no equilibrium strategy in *SUB* and *PAT*) and 50 are chosen frequently (50 is even the most chosen investment level in *NO* and *PAT* in the first round). Possible explanations for this observation might be that those investment levels are prominent numbers and, moreover, that an investment

[34] Besides behavior that is consistent with asymmetric equilibria, we observe 'local maxima' in all three treatments, which occur in 5-scale increments. By local maxima we mean investment levels which are chosen more frequently compared to investment levels slightly below and slightly above these maxima (e.g., in the range from 50 to 60 investments of 50, 55 and 60 are chosen in more cases than intermediate investment levels). This may be explained by the prominence level of numbers (see Albers (2001)) as these investment level increments seem to create focal points.

Table 6: Discrete symmetric and asymmetric Nash equilibrium investment levels

Treatment		Investment decision		
		r_i	r_j	r_k
NO	Symmetric	25	25	25
	Asymmetric	All combinations of investment levels [20,...,30] that add up to 75, without (25,25,25)		
		0	0	99
SUB	Symmetric	37	37	37
	Asymmetric	0	0	99
PAT	Symmetric	37	37	37
	Asymmetric	0	0	99

All asymmetric equilibria are given in Table 12 in Appendix A.4.

of 25 gives a 50% chance of a successful innovation, which might also create a focal point. However, note that an investment level of 25 is chosen much more frequently in *NO* – where it is the symmetric equilibrium level. Thus, at least a part of this percentage in *NO* seems to be driven by equilibrium investment behavior. Furthermore, the fraction of the chosen symmetric Nash equilibrium level of 25 in *NO* remains constant from the first third till the last third (although it is lower in the first round in which the most chosen investment level is 50). In general, in all treatments non-equilibrium investment levels decrease over rounds and there seems to be a tendency to converge to the asymmetric equilibria (0, 0, 99). Especially the fraction of zero investment, which belongs to an asymmetric equilibrium strategy, increases. Specifically, in *SUB* non-equilibrium levels (in particular choosing 50) decrease over rounds converging to the extreme points 0 and 99 and also the *PAT* treatment clearly indicates that the extreme investment levels 0 and 99 are chosen more frequently in later rounds (non-equilibrium levels decrease in favor of 0 and 99).

ER Investment Levels

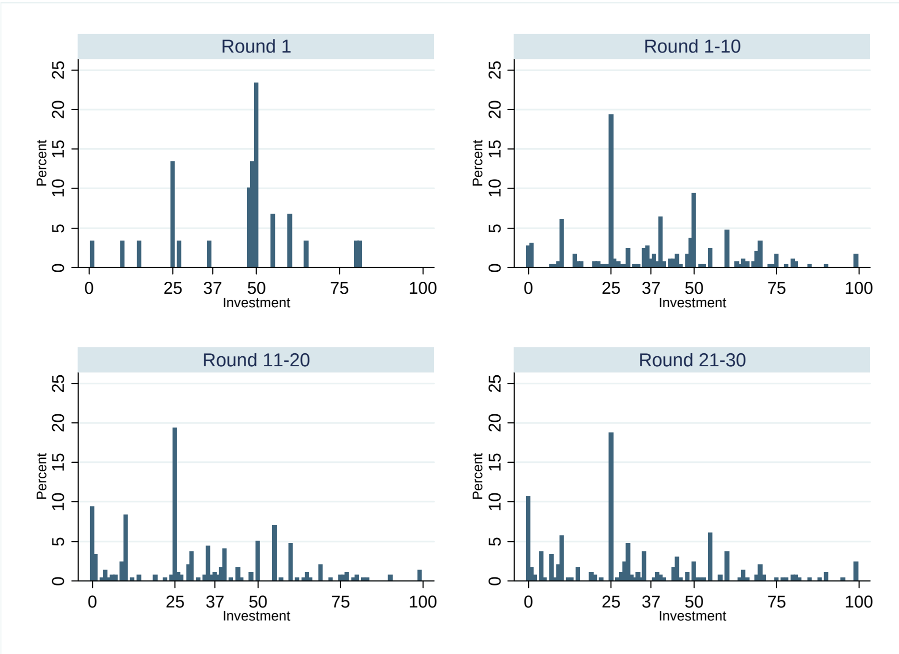
Result 4.1. *Concerning the investment levels the experimental data show the following:*

- *The introduction of each policy instrument (SUB and PAT) significantly increases the investment level compared to no governmental R&D intervention (by 35.79% and 45.62% compared to a theoretical increase of 48.64%), which is in favor of Hypothesis 3.1.*
- *As compared to the Nash predictions, firms overinvest in R&D with and without R&D policy instruments.*

Result 4.2. *The dynamics of R&D investment decisions are very similar between treatments: previously successful innovation has a positive effect on current investment decisions independent of other firms' success. Moreover, investment levels* *increase strongest if a firm was the exclusive innovator in the previous round and if patent protection is implemented.*

Result 4.3. *In NO, the modal R&D investment level is indeed the predicted level of 25, whereas the modal level of 99 in SUB and PAT is different from the predicted 37. The second and third most frequently chosen levels are 0 and an intermediate level of 50 in PAT, and 50 and 0 in SUB. These observations might be (partly) explained by asymmetric equilibria. Investment levels tend to converge to the asymmetric equilibrium levels of 0 and 99 over rounds.*

Figure 3: Dynamic view on investment level choices – *NO*



4.2 Cost Structure, Prices, and Profits

4.2.1 Cost Structure

The cost structure in the first Bertrand market period (i.e., the number of firms facing low costs of 100 and the number of firms facing high costs of 500) is determined by the number of successful innovations. The cost structure in the second Bertrand market period depends on the cost structure of the first market as well as on the chosen policy instrument. Table 7 gives observed frequencies of the different cost structures in the two Bertrand market periods (and as a benchmark predicted frequencies in case of symmetric discrete equilibrium investment levels). Only in the *PAT* treatment the innovating firms are protected against imitation. Thus, in this

Figure 4: Dynamic view on investment level choices – *SUB*

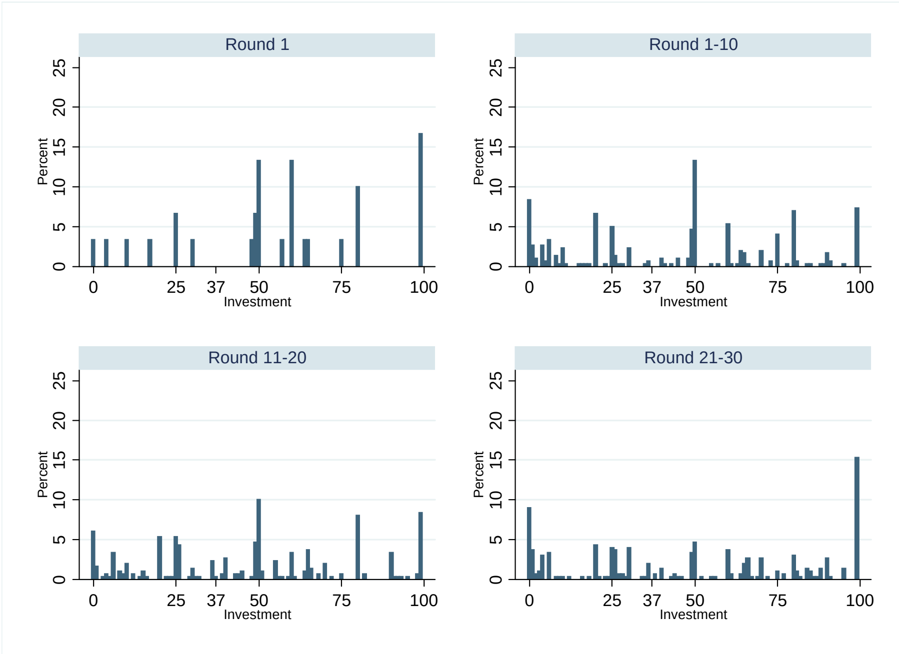
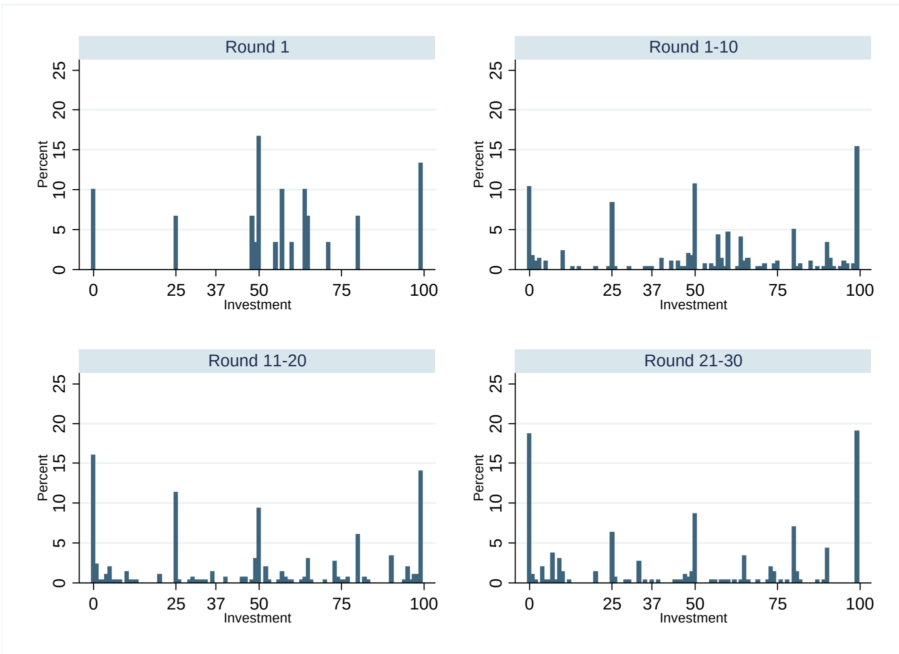


Figure 5: Dynamic view on investment level choices – *PAT*



treatment the number of low cost firms does not change in the $2nd$ market. In the other two treatments however, in the second market period there are either three firms with high costs (if in the first market period there was no low cost firm in the market) or three firms with low costs (in all other cases). Markets with two or three low cost firms occur more often in *SUB* and *PAT* than in *NO* after the investment stage. Moreover, we observe the extreme case of three high cost firms (see column 'zero' in the $1st$ period) twice as often in the baseline treatment as in *SUB* and *PAT*. The higher percentage of successfully innovating firms in a market is a result of the higher investment levels in treatments with policy instruments.

Table 7 reveals only slight differences in observed proportions of cost structures as compared to those predicted by symmetric R&D investment strategies.[35] Specifically, predicted proportions are always higher than observed proportions if there is no low cost firm in the market in all three treatments, whereas the chances of two or three low cost firms in a market are typically higher than predicted.[36] This observation can be explained by the observed overinvestment in all three treatments. The observed frequency of a sole low cost firm is smaller than predicted in *NO* and *SUB*, but higher in *PAT*. Theoretically, *SUB* and *PAT* should result in identical frequencies of cost structures in the first market. Note however, that in *SUB* more successful innovations occur than in *PAT* (the percentage of two and three low cost firms is higher and the percentage of no or one low cost firm is lower in *SUB*).

4.2.2 Prices and Mark-ups

Figure 6 depicts the average market price (i.e., the lowest price $p_{i,t}^{min} = \min[p_{1,t}, p_{2,t}, p_{3,t}]$ set in each market) for the three treatments for both market periods. Obviously, observed market prices in the experiment are on average close to those theoretically predicted (if subjects choose discrete symmetric equilibrium investment levels and equilibrium market prices).

Under Bertrand competition market prices are mainly driven by the underlying cost structure. Therefore, Table 8 presents the average of actual market prices in the $1st$ and $2nd$ Bertrand markets for each cost structure separately.[37] Again, in all

[35] This is a surprising result. Although the majority of individual behavior is not consistent with the discrete symmetric equilibrium investment level, on average similar market structures result as predicted by the symmetric Nash equilibrium.

[36] However, Chi-square goodness-of-fit tests yield no significant differences on the 10%-level in observed and predicted frequencies for all three treatments in the first market period (- values are given by 4.60, 4.48 and 3.24 in NO, SUB and PAT). It is not possible to calculate Chi-square tests for the second period as there are parameter values equaling zero in NO and SUB.

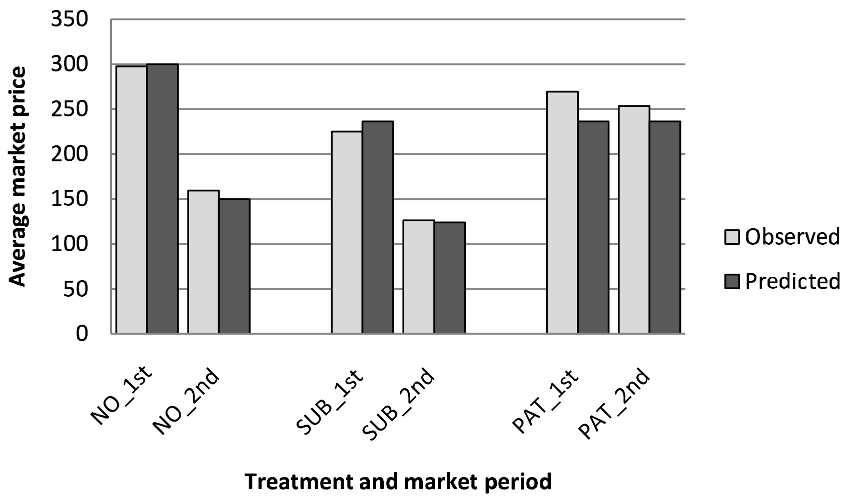
[37] We proceed in the following way: After the investment stage four different states of nature may occur - the numbers of successful innovations before Bertrand market starts are either zero, one, two or three. We calculate for these four different cases the average of *lowest* prices over all rounds

Table 7: Observed (predicted) cost structure in the Bertrand markets

Bertrand markets	Treatment	Number of low cost firms 1st period Zero	One	Two	Three	Total
1st	*NO*	11.67%	32.33%	41.33%	14.67%	100%
		(12.50%)	(37.50%)	(37.50%)	(12.50%)	(100%)
	SUB	4.67%	24.00%	48.67%	22.67%	100%
		(6.01%)	(28.00%)	(43.48%)	(22.51%)	(100%)
	PAT	5.67%	29.67%	46.33%	18.33%	100%
		(6.01%)	(28.00%)	(43.48%)	(22.51%)	(100%)
		Number of low cost firms 2nd period Zero	One	Two	Three	Total
2nd	*NO*	11.67%	0.00%	0.00%	88.33%	100%
		(12.50%)	(0.00%)	(0.00%)	(87.50%)	(100%)
	SUB	4.67%	0.00%	0.00%	95.30%	100%
		(6.01%)	(0.00%)	(0.00%)	(93.99%)	(100%)
	PAT	5.67%	29.67%	46.33%	18.33%	100%
		(6.01%)	(28.00%)	(43.48%)	(22.51%)	(100%)

The number of low cost firms indicates how many of the three competing firms in each Bertrand market attain low cost of 100. Predicted cost structure taking discrete symmetric Nash equilibrium investment levels of 25 in *NO* and 37 in *SUB* and *PAT* are given in parentheses.

Figure 6: Average market price



The average market price was derived by taking the observed (predicted) frequency of each cost structure after the investment stage (see Table 7) and multiplying these probabilities with the observed (predicted) average lowest prices of each cost structure. Note that the average market price thus includes all different cost structures.

three treatments average market prices are close to those theoretically predicted. If there are only high cost firms in the market (column 1) prices are slightly above 500 in all three treatments (in the $1st$ market slightly higher prices are set than in the $2nd$ market). If there is one low cost firm in the first market (column 2), prices are set again close to those theoretically predicted. One low cost firm in the first market means three low cost firms in the second market due to imitation in *NO* and *SUB*. Thus, prices drop close to 100 except for the *PAT* treatment, where innovation is protected (prices stick to nearly 499). In case of two successfully innovating firms market prices in the first market period are between 127.77 and 149.20 on average, depending on the treatment (column 3). This cost structure implies that there are in the second market three low cost firms again in *NO* and *SUB* and still two low cost firms in *PAT*. The last column gives the average lowest prices if there are three low cost firms in the $1st$ and thus also three low cost firms in the $2nd$ market in all three treatments. In case of zero, two as well as three low cost firms prices are lower in the $2nd$ than in the $1st$ market period. Moreover, prices are higher than theoretically predicted in all cases, except the case that one firm has low costs and the other two firms have high costs.[38] Figures 10 to 12 in Appendix A.3 depicts average lowest prices for each cost structure in the $1st$ and $2nd$ Bertrand markets for each round. The figure shows that average market prices converge to the Bertrand equilibrium prices over rounds as well as over market periods: First, average prices in general converge to the equilibrium price over rounds and second, prices in the $2nd$ market are nearly always set closer to the equilibrium price than those of the corresponding $1st$ market.

With the average lowest price (market price) for each cost structure given by Table 8 we can derive the expected mark-ups of firms depicted in Table 15 [39]. The finding that prices and thus mark-ups are higher if there are only two low cost firms in the market is consistent with what has been observed in previous Bertrand market experiments: E.g., Dufwenberg and Gneezy (2000) find that the number of competing firms with identical marginal costs influences the fierceness of competition in a Bertrand oligopoly experiment. Their data provide evidence that prices converge towards the theoretical prediction when there are groups of three or four competitors, whereas prices are much higher than predicted when only two competitors are matched. Hence, these observations can be explained by the

separately for the $1st$ and for the $2nd$ market. Note that the labeling 'Number of innovating firms' alludes only to the number of low cost firms at the beginning of the first market period, not to the second market period (where number of low-cost firms might differ due to imitation).

[38] Slightly higher prices in these cases might be explained by the fact that in the discrete case firms can achieve positive profits even if they are not the only innovating firm with low costs. Note that in the discrete case 501(and 101) are also equilibrium prices for zero (two and three) innovating firms.

[39] Note that only those firms benefit from the mark-up who set the lowest price in their market.

Table 8: Average of lowest prices observed (predicted) in the Bertrand markets

Bertrand markets	Treatment	Number of innovating firms			
		Zero	One	Two	Three
1st	*NO*	508.37 (500)	494.37 (499)	146.13 (100)	124.14 (100)
	SUB	507.36 (500)	473.00 (499)	127.77 (100)	112.69 (100)
	PAT	519.29 (500)	493.88 (499)	149.20 (100)	131.36 (100)
2nd	*NO*	504.66 (500)	113.39 (100)	114.23 (100)	113.55 (100)
	SUB	504.93 (500)	107.26 (100)	108.77 (100)	106.12 (100)
	PAT	504.53 (500)	494.99 (499)	124.48 (100)	111.13 (100)

The number of innovating firms indicates the successfully innovating firms after the investment stage (i.e., low cost firms in the first market period), but does not refer to imitating firms in the second market period. Note that in case of a sole low cost firm the discrete equilibrium price is 499, otherwise the sole innovator runs the risk of sharing the demand and decreasing his profits considerably.

influence of market concentration (of firms with identical low costs) on price setting. For a detailed analysis of the mark-ups please refer to Appendix A.2.

4.2.3 Profits

This subsection surveys the profits of the firms. We differ between profits achieved solely at the market stage and profits over both stages of the game: *Market profits* (given separately for the *first period*, *second period*, and *both periods*) refer to the actually realized profit per firm at the market stage and *round profits* defined as *endowment - investment cost + market profits over both periods* give profits over both stages (including the investment and the market stage). Table 9 gives average market profits over rounds for both periods separately and in sum.[40]

For each specific cost structure after the investment stage $\pi_i(c_{i,1}^H)$ and $\pi_i(c_{i,1}^L)$ denote firm i's profits depending on its marginal costs (e.g., $(c_{i,1}^H)$ refers to firm i starting with high marginal costs after the investment stage in market period $t = 1$). Note that in *NO* and *SUB* in case of one and two low cost firms after the investment stage all three firms face low costs in the 2*nd* market period due to imitation. Table 9 summarizes average total market profits per firm for all cost structures as well as market profits per firm separately for low and high cost firms if both types share a market. Total market profits give the average profit of a market per firm for each

[40] Note that there is a difference between mark-ups and market profits. Mark-up refers to the potential profit margin in a market with a specific cost structure, thus measuring a firm's profit margin if a single firm sets the lowest price. Since mark-ups present the potential profit margin they can be interpreted as incentives to innovate in order to enable a firm to set the lowest price in the market. Average market profits, however, refer to the sum of actually realized profits in a market *divided by the number* of firms, thus measuring the average profit per firm (including also the 'losing' firms). Hence, average market profits can be seen as the expected profit a firm could obtain ex ante.

Table 9: Average market profits per high and low cost firms

	Number of innovating firms							
	Zero	One			Two			Three
Treatment	$\pi_i(c^H_{i,1})$	$\pi_i(c^L_{i,1})$	$\pi_i(c^H_{i,1})$	Total	$\pi_i(c^L_{i,1})$	$\pi_i(c^H_{i,1})$	Total	$\pi_i(c^L_{i,1})$
NO (1st period)	2.79	390.25	0.00	130.08	21.45	0.00	14.30	8.05
SUB (1st period)	2.45	367.44	0.00	122.48	13.89	0.00	9.26	4.23
PAT (1st period)	6.43	389.38	0.00	129.79	24.60	0.00	16.40	10.45
NO (2nd period)	1.55	5.49	3.95	4.46	3.99	6.25	4.74	4.52
SUB (2nd period)	1.64	1.76	2.75	2.42	2.33	4.10	2.92	2.04
PAT (2nd period)	1.51	389.93	0.28	130.16	12.24	0.00	8.16	3.71
NO (both)	4.34	395.74	3.95	134.55	25.44	6.25	19.05	12.56
SUB (both)	4.10	369.21	2.75	124.90	16.22	4.10	12.18	6.27
PAT (both)	7.94	779.31	0.28	259.96	36.84	0.00	24.56	14.16

cost structure (which naturally equals profits of solely high (low) cost firms in zero (three)). Concentrating on average total market profits over both market periods (which can be interpreted as a firm's expected profit at the market stage before it gets to know if it successfully innovates or not) it holds again for each possible cost structure that firms benefit most from *PAT* and achieve lowest profits in *SUB* as theoretically predicted (for this matter refer also to the following subsection).

Now we take a look on firms' average round profits including the investment stage. We can interpret the average round profits as the expected profits a firm can gain in general in a specific treatment per round (regardless of a specific cost structure). As round profits measure the ex ante expected profit, they indicate which treatment is most profitable for firms. Table 10 summarizes the average (predicted) profits of all firms over all rounds for the three treatments. Note that round profits (observed as well as predicted) are smallest in *SUB*, however profits do not differ significantly between treatments. A Kruskal-Wallis test as well as pair-wise Mann-Whitney-U tests reveal no significant differences in average profits across treatments using matching groups.[41]

ER Cost Structures, Prices and Profits:

Result 4.4. *The predicted and observed proportions of market structures show only slight differences.*

Result 4.5. *Average market prices converge to predicted Bertrand market prices (over rounds as well as over subsequent market periods). This results in mark-ups (and thus the incentive to invest in R&D) being highest in PAT (over the two market*

[41] Kruskal-Wallis test yields p=0.171 and pair-wise one-tailed Mann-Whitney-U tests yield p=0.274 (*NO-SUB*), p=0.075 (*NO-PAT*) and p=0.075 (*SUB-PAT*).

Table 10: Average observed and predicted round profits

Round profits	*NO*	*SUB*	*PAT*
Observed	119.25	114.11	141.34
	(119.92)	(102.85)	(226.07)
Predicted	124.88	118.74	137.48

Standard deviations are given in parentheses. To calculate predicted levels we use the discrete symmetric equilibrium (25 in *NO* and 37 in *SUB* and *PAT*) and $\Delta c = 399$.

periods). Observed mark-ups of a sole low cost firm are somewhat lower than in Nash equilibrium and mark-ups are somewhat higher when there are zero, two, or three low cost firms.

Result 4.6. *Firms' profits are highest in PAT and lowest in SUB (although we find no significant difference), which confirms the tendency of firms' interest as stated in Hypothesis 3.3.*

4.3 Welfare Effects

In this subsection, we examine the effects of subsidies and patents on welfare at the society level and at the level of interest groups (i.e., consumers, firms,[42] and government). For each treatment Table 11 gives observed and predicted (in parentheses) added welfare as compared to a benchmark situation in which all firms make zero-R&D investments. There are three main observations: First, in comparison to zero-investments in R&D, total social welfare (as well as total consumer surplus and total firms' profits) increases intensely if firms invest in R&D with and without R&D instruments (which is shown by the fact that all added values in all treatments are positive). Second, if firms invest in R&D, added social welfare (*NO*: 600.56; *SUB*: 620.88; and *PAT*: 601.38) does not differ significantly between our treatments,[43] which implies that added social welfare cannot be enhanced by the introduction of policy instruments. However, subsidies and patents have very different consequences for the distribution of welfare within society. As compared to the situation without R&D policy (*NO*), on the one hand subsidies increase consumer welfare by 105.95

[42]Note that we refrain from including the firms' experimental endowment of 100 in the producer rent in contrast to round profits presented in Table 10 in the last subsection. Here we use instead the formula of rents given in Appendix A.1.

[43]Using added welfare per matching group a Kruskal-Wallis test yields $p>0.5$ and two-tailed Mann-Whitney-U tests $p>0.1$ for each comparison. Note however, that a replication of the experiment would be reasonable in order to check the robustness of results by getting more independent observations.

points and on the other hand they reduce industry profits by 15.42 points and government budget by 70.23 points. In contrast, patents decrease consumer welfare by 65.47 points, leave the government budget unaffected, and increase firms' profits by 66.29 points.[44] Third, observed added social welfare and added welfare shares are lower than the theoretically predicted values (besides consumer rent in *SUB* and producer rent in *PAT*),[45] which can be explained by the overinvestment mentioned above. This result implies that those interest groups which are anyway privileged by a policy instrument (consumers in *SUB* and firms in *PAT*), realize even higher rents than predicted at the expense of the already disadvantaged group.

However, it remains the problematical question what practical implications can actually be derived. Our welfare results have to be interpreted with caution as our model and experimental setting are subject to some limitations which deserve mention: We neglected the funding of subsidies (for instance, in our model government budget is not linked to consumers by tax) and further patent costs (which occur due to the possible monopoly position of an innovating firm with patent protection: e.g., future welfare might decrease as firms' incentives decrease to invest in future R&D projects). For these reasons a complete welfare analysis is beyond the scope of this paper. But even in our simplified framework it can be shown that the decisions of whether and which R&D policy should be introduced seem to be sensitive to the political process of interests.

ER Welfare Effects

Result 4.7. *R&D subsidies and patents do not increase social welfare significantly (due to overinvestment), thus we question Hypothesis 3.2. However, we observe an (although not significant) tendency that both policy instruments cause redistribution within society. With subsidies, consumers gain welfare at the expense of industry profits and government budget. With patents, the industry increases profits at the expense of consumer welfare. These results seem to support Hypothesis 3.3.*

[44] The increase in consumer rent if *SUB* is introduced compared to *NO* is significant at the 1%-level (one-tailed Mann-Whitney-U test). All other comparisons do not yield significant differences. This result might be partly driven by a small sample size of only 5 independent observations.

[45] CR in *SUB* is higher than expected, because more successful innovations take place than theoretically predicted (compare Table 7: theoretically *SUB* and *PAT* should provide identical cost structures (due to the Nash equilibrium of 37 in both treatments), however more successful innovations occur in *SUB* for two and three firms). In *PAT* we observe a higher than predicted frequency of one low cost firm in the market which might explain the higher PR.

Table 11: Average welfare effects

	Added welfare - observed (predicted)			
Treatment	Social welfare	Consumers	Producers	Government
NO	600.56 (623.25)	542.83 (548.63)	57.74 (74.63)	0.00 (0.00)
SUB	620.88 (639.03)	648.78 (638.31)	42.32 (56.23)	-70.23 (-55.50)
PAT	601.38 (639.03)	477.36 (526.58)	124.03 (112.45)	0.00 (0.00)

To calculate predicted levels we use the discrete symmetric equilibrium (25 in *NO* and 37 in *SUB* and *PAT*) and $\Delta c = 399$.

5 Conclusion

This paper investigates the performance of two prominent policy instruments used to enhance firms' investments in R&D: subsidies and patents. A successful R&D innovation entails lower marginal costs for the innovating firm. We use a two-stage stochastic R&D model with an investment stage followed by a Bertrand price competition stage with two market periods and derive equilibrium investments and prices for our experimental parameters. In equilibrium, both patents and subsidies induce the same amount of R&D investment, which is higher than the investment without governmental incentives. To test these theoretical predictions we run an experiment comparing a baseline treatment without any policy instrument with two treatments in which either subsidies are paid to investing firms or in which innovating firms are granted patent protection respectively. Our main finding at the investment stage is a significant increase in investment levels if a policy instrument is implemented. Thus, our experiment provides evidence that both instruments are effective in promoting investments in R&D.[46] However, we observe overinvestment in all three treatments. This overinvestment might be on the one hand explained by asymmetric discrete equilibrium investment levels (especially those in which one firm invests the maximal amount and two other firms refrain from investing) and a simple coordination failure of the subjects. On the other hand, this result might be (also) due to the specific properties of a Bertrand market: a Bertrand market leads to 'aggressive' interaction among vigorous competitors. Competition in a Bertrand market is very strong in the sense that a firm makes zero-profits for sure if it does not become the

[46]Theoretically both introducing a subsidy as well as patent protection should increase the investment level by the same amount compared to the situation in which no policy instrument is used. This is supported by our experimental results as the investment level does not differ significantly across the treatments *SUB* and *PAT*.

only innovator in the market.[47] Maybe this all-or-none property tempts subjects into overinvesting in R&D.

Concerning the market stage we observe that although prices are set slightly above the marginal costs, they converge to the theoretically predicted Bertrand equilibrium prices both over rounds as well as over market periods. In general, note that despite the complex experimental setting (like implementing a two-stage game with endogenously determined profits), theory predicts outcomes *on average* quite well although individual investment behavior diverges from the predicted symmetric Nash equilibrium: e.g., market structures, average market prices, and average profits are close to the theoretically predicted levels.

Our data show that R&D investment increases added social welfare compared to no R&D investment, but also exposes that R&D subsidies as well as patents do not strongly affect social welfare compared to no policy instrument. This result is driven by the observed overinvestment discussed above. However, both policy instruments cause substantial redistribution within society. Firms fare better under patents than under no policy, the latter still yields higher profits than subsidies. The investigation of different 'interest groups' is important for policy analysis, because it reveals where support and opposition can be expected. Nevertheless, the described results should be interpreted carefully. Due to several limitations of our model an extensive welfare analysis is beyond the scope of this paper. Limitations of our analysis are the following: we do not include funding of the instruments, i.e., taxes would change the consumer surplus, for instance, nor do we take the costs of granting patent protection into account. Patents have two effects on social welfare: on the one hand they provide incentives to innovate in R&D, but on the other hand they might create monopolies. If a firm holds a monopoly position this could in turn inhibit near-term following innovations.[48] These intertemporal aspects are neglected in our static framework analysis. Thus, as it is shown by Bessen and Maskin (2009), patents may be desirable to encourage innovation in a static setting (e.g., in their static model a patent protection leads to higher profits of a firm undertaking R&D as well as to higher welfare), but they might actually inhibit complementary innovation in a sequential setting in which imitation might even become a spur to innovation. Scotchmer (1991) also notes that including positive externalities and in-

[47]Expecting Bertrand competition at the second stage creates a kind of the-winner-takes-all situation at the investment stage. Patent race literature suggests that non-colluding firms invest excessively in R&D (for a seminal paper see Loury (1979)). Doraszelski (2008) shows that this result strongly hinges on the winner-takes-all assumption. If this assumption is relaxed and patent protection becomes less effective firms might even underinvest in R&D.

[48]Note however, that this effect is alleviated by our design as it is possible that more than one firm successfully innovates. Therefore, patent protection in our experiment does not automatically imply monopoly power of an innovating firm.

tertemporal knowledge spillovers, which early innovators confer on later innovators, poses new problems for the optimal design of patent law. Furthermore, our model lacks R&D coordination and cooperation (like cross-licensing agreements and joint ventures), which is very common in R&D intensive markets (compare e.g., Morasch (1995)). All these factors might have an essential influence on the impact of policy instruments on R&D investment and their successful implementation and should be investigated in future research.

Hence, further research is to be done on the robustness of our results concerning the effects of the policy instruments on investment behavior. Of course, our results cannot yield conclusive evidence for policy implications as we simplified the model a lot. However, our experiment is a first step and its insights might contribute to a broader research agenda on R&D investment promoting policy instruments: Our findings suggest that the tested policy instruments serve the purpose of rising investments and that the choice of an appropriate instrument depends on the political process of interests.

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Appendix

A.1 Mathematical Appendix

A.1.1 Proofs

Proof of Proposition 2.1 Firm i's expected total profit is given by

$$\pi_i^e(r_i, r_{-i}) = F(r_i)\left[1 - F(r_{-i})\right]^{n-1}(1+\theta)\Delta c - (1-\sigma)r_i,$$

where Δc gives i's mark-up if it is the only low cost firm, which occurs with probability $F(r_i)\left[1 - F(r_{-i})\right]^{n-1}$ for $1+\theta$ periods, and $(1-\sigma)r_i$ gives its R&D costs net of subsidy.[49] Maximization of i's expected total profit with respect to r_i yields

$$\frac{\partial \pi_i^e(r_i, r_{-i})}{\partial r_i} = f(r_i^*)\left[1 - F(r_{-i})\right]^{n-1}(1+\theta)\Delta c - (1-\sigma) \stackrel{!}{=} 0, \ \forall i.$$

Rearranging and assuming symmetry, i.e., $r_i{=}r$, $\forall i$, yields condition (1) as stated in our proposition:

$$f(r^*)\left[1 - F(r^*)\right]^{n-1}(1+\theta)\Delta c = 1 - \sigma,$$

where the left-hand and right-hand sides (henceforth *LHS* and *RHS*, respectively) give the expected marginal revenues MR^e, and marginal costs *MC*, of R&D investment, respectively. Comparative static analysis with each of the parameters $\Delta c, \theta$ and n is conducted like follows: We can rewrite condition (1) as $g(x, r(x)) = c$, where the *LHS* is a function of $x \in (\Delta c, \theta, n)$, which is the parameter of interest, and the investment level r. The *RHS* is a constant c. A marginal change in x leads to $\frac{dg}{dx} + \frac{dg}{dr}\frac{dr}{dx} = 0$. We are interested in $\frac{dr}{dx}$. Note that *LHS* is strictly decreasing in r ($\frac{dg}{dr} < 0$), because:

$$\frac{\partial LHS}{\partial r} = \left[f'(r)\left[1 - F(r)\right]^{n-1} - (n-1)f(r)^2\left[1 - F(r)\right]^{n-2}\right](1{+}\theta)\Delta c < 0 \quad for\ r\ \in (0,1)$$

with $f'(r)[1 - F(r)]^{\text{ n}-1} < 0$ and $(n-1)f(r)[1 - F(r)]^{\text{ n}-2} > 0$.
We derive for each specific x the derivative $\frac{dg}{dx}$ and thus can conclude whether $\frac{dr}{dx}$ must be increasing or decreasing. The procedure is analogous for the comparative statics with the parameter σ: Here we use the first order condition: $f(r_i^*)\left[1 - F(r_{-i})\right]^{n-1}(1+\theta)\Delta c - (1-\sigma) \stackrel{!}{=} 0$, which can be rewritten as $g(x, r(x)) = c$ again.
This analysis exposes the following influence of each parameter on the optimal investment level r:

- *Mark-ups:* For a change in Δc, $\frac{dg}{d\Delta c} > 0$ and thus $\frac{dr}{d\Delta c} > 0$ which implies that the equilibrium value of r increases if Δc increases.
- *Patent-protected market periods:* For a change in θ, $\frac{dg}{d\theta} > 0$ and thus $\frac{dr}{d\theta} > 0$ which implies that the equilibrium value of r increases if θ increases.
- *Subsidy:* For a change in σ, $\frac{dg}{d\sigma} > 0$ and $\frac{dg}{dr} < 0$ and thus $\frac{dr}{d\sigma} > 0$ which implies that the equilibrium value of r increases if σ increases.

[49] A discount factor for the profits realized in subsequent rounds is neglected.

- *Number of firms:* For a change in n, $\frac{dg}{dn} < 0$. Since $\frac{dg}{dr} < 0$ it holds that $\frac{dr}{dn} < 0$ which implies that the equilibrium value of r decreases if n increases.

- *Number of market periods:* Finally, the equilibrium value of r is independent of the number of market periods, T, because a firm can only receive strictly positive Nash equilibrium market profits if it is the only low cost firm. In our model the number of market periods in which this low cost firm can make such profits is entirely determined by the first period and the additional number of patent-protected market periods θ. However, T is the upper boundary of θ and thus may have an indirect effect on r^*.

Proof of Proposition 2.2 If firms choose the symmetric Nash equilibrium investment level, this yields the following implications for added welfare shares of different interest groups. Note first that the investment level r is strictly increasing in σ and θ as was shown in Proposition 2.1 ($\frac{dr}{d\sigma} > 0$ and $\frac{dr}{d\theta} > 0$). In the following we first present the derivatives of welfare shares with respect to σ, then with respect to θ. The added government rent is given by

$$GR(r^*, \sigma) = -nr^*\sigma \quad (2).$$

Hence, an increase in the subsidized proportion σ yields

$$\left.\frac{\partial GR(r^*, \sigma, \theta)}{\partial \sigma} = -n\sigma\frac{dr^*}{d\sigma} - nr^* < 0. \quad\right\} \text{ transfer to PR}$$

Moreover, expected added consumer rent is given by[50]

$$\begin{aligned} CR^e(r^*, \theta, \sigma) \quad &= \quad nF(r^*)\left[1 - F(r^*)\right]^{n-1}(T - 1 - \theta)\Delta c \\ &\quad + \textstyle\sum_{k=2}^{n}\binom{n}{k}F(r^*)^k\left[1 - F(r^*)\right]^{n-k}T\Delta c, \end{aligned}$$

which can be rewritten as

$$\begin{aligned} CR^e(r^*, \theta, \sigma) \quad &= \quad T\Delta c - \left[1 - F(r^*)\right]^n T\Delta c \\ &\quad -nF(r^*)\left[1 - F(r^*)\right]^{n-1}(1 + \theta)\Delta c. \end{aligned} \qquad (3)$$

This yields

$$\begin{aligned} \tfrac{\partial CR^e(r^*, \theta, \sigma)}{\partial \sigma} \quad &= \quad T\Delta cnf(r^*)\tfrac{dr^*}{d\sigma}\left[1 - F(r^*)\right]^{n-1} \\ &\quad \left. -n(1+\theta)\Delta cf(r^*)\tfrac{dr^*}{d\sigma}\left[1 - F(r^*)\right]^{n-2}\left[\left[1 - F(r^*)\right] - (n-1)F(r^*)\right] \;.\right\} \text{ transfer to PR} \end{aligned}$$

Finally, expected added producer rent is given by

$$PR^e(r^*, \theta, \sigma) = nF(r^*)\left[1 - F(r^*)\right]^{n-1}(1 + \theta)\Delta c - n(1 - \sigma)r^* \quad (4).$$

Hence, we have

$$\begin{aligned} \tfrac{\partial PR^e(r^*, \theta, \sigma)}{\partial \sigma} \quad &= \quad \left. n(1+\theta)\Delta cf(r^*)\tfrac{dr^*}{d\sigma}\left[1 - F(r^*)\right]^{n-2}\left[\left[1 - F(r^*)\right] - (n-1)F(r^*)\right]\right\} \text{ transfer from CR} \\ &\quad \left. +nr^* + n\sigma\tfrac{dr^*}{d\sigma}\right\} \text{ transfer from GR} - n\tfrac{dr^*}{d\sigma}. \end{aligned}$$

[50]For a derivation of the added consumer rent see Mathematical Appendix A.1.2.

Now we concentrate on an increase of the number of patent-protected periods θ. Concerning government rent this yields

$$\left.\frac{\partial GR(r^*,\sigma,\theta)}{\partial\theta} = -\,n\sigma\frac{dr^*}{d\theta} < 0.\quad\right\}\quad \text{transfer to PR}$$

Note that $\frac{\partial GR(r^*,\sigma,\theta)}{\partial\theta} = 0$ if we consider 'pure' instruments (i.e., $\sigma = 0$ if patent protection is on hand).

The derivatives of CR^e and PR^e with respect to θ are given by

$$\begin{aligned}
&\frac{\partial CR^e(r^*,\theta,\sigma)}{\partial\theta}\\
&\quad = T\Delta cnf(r^*)\frac{dr^*}{d\theta}\left[1-F(r^*)\right]^{n-1}\\
&\quad \left.\begin{aligned}&- n(1+\theta)\Delta cf(r^*)\tfrac{dr^*}{d\theta}\left[1-F(r^*)\right]^{n-2}\left[\left[1-F(r^*)\right]-(n-1)F(r^*)\right]\\ &- n\Delta cF(r^*)\left[1-F(r^*)\right]^{n-1}\end{aligned}\right\}\text{transfer to PR}
\end{aligned}$$

and

$$\begin{aligned}
&\frac{\partial PR^e(r^*,\theta,\sigma)}{\partial\theta}\\
&\quad \left.\begin{aligned}&= n(1+\theta)\Delta cf(r^*)\tfrac{dr^*}{d\theta}\left[1-F(r^*)\right]^{n-2}\left[\left[1-F(r^*)\right]-(n-1)F(r^*)\right]\\ &+n\Delta cF(r^*)\left[1-F(r^*)\right]^{n-1}\end{aligned}\right\}\text{transfer from CR}\\
&\quad \left.+n\sigma\frac{dr^*}{d\theta}\right\}\text{transfer from GR}\\
&\quad -\,n\frac{dr^*}{d\theta}
\end{aligned}$$

Then, our proposition holds, because there is rent shifting both between firms and government as well as between firms and consumers as indicated by curly brackets. More precisely, the first term of PR equals the second term of CR and the decrease of GR equals the increasing second term in PR. This is valid for an increase in the subsidized proportion as well as for an increase in the number of patent-protected periods.

A.1.2 Derivations

Derivation Added Consumer Rent Expected total consumer rent if firms invest is given by:

$$\begin{aligned}
\text{Total } R^e(r,\theta,\sigma) &= nF(r)\left[1-F(r)\right]^{n-1}(T-1-\theta)(\bar{p}-c^L)\\
&+ nF(r)\left[1-F(r)\right]^{n-1}(1+\theta)(\bar{p}-c^H)\\
&+ \textstyle\sum_{k=2}^{n}\binom{n}{k}F(r)^k\left[1-F(r)\right]^{n-k}T(\bar{p}-c^L) \qquad \text{(A1)}\\
&+ (1-F(r))^n(\bar{p}-c^H)T
\end{aligned}$$

Total consumer rent if no firm invests in R&D (benchmark situation) is given by: $(\bar{p}-c^H)T$. Thus, subtracting the benchmark situation from the expected total CR results in an expected added consumer rent of:

$$\begin{array}{rcl} CR^e(r,\theta,\sigma) & = & nF(r)\,[1-F(r)]^{n-1}\,(T-1-\theta)(\bar{p}-c^L) \\ & + & nF(r)\,[1-F(r)]^{n-1}\,(1+\theta)(\bar{p}-c^H) \\ & + & \sum_{k=2}^{n}\binom{n}{k}F(r)^k\,[1-F(r)]^{n-k}\,T(\bar{p}-c^L) \\ & + & (1-F(r))^n(\bar{p}-c^H)T \\ & - & (\bar{p}-c^H)T \end{array} \quad \text{(A2)}$$

This expression can be rewritten as:

$$\begin{array}{rcl} CR^e(r,\theta,\sigma) & = & nF(r)\,[1-F(r)]^{n-1}\,(T-1-\theta)((\bar{p}-c^L)-(\bar{p}-c^H)) \\ & + & nF(r)\,[1-F(r)]^{n-1}\,(1+\theta)((\bar{p}-c^H)-(\bar{p}-c^H)) \\ & + & \sum_{k=2}^{n}\binom{n}{k}F(r)^k\,[1-F(r)]^{n-k}\,T((\bar{p}-c^L)-(\bar{p}-c^H)) \\ & + & (1-F(r))^n((\bar{p}-c^H)-(\bar{p}-c^H))T \end{array} \quad \text{(A3)}$$

because $(T-1-\theta)+(1+\theta)=T$ and $nF(r)\,[1-F(r)]^{n-1}+\sum_{k=2}^{n}\binom{n}{k}F(r)^k\,[1-F(r)]^{n-k}+(1-F(r))^n=1$. (A3) yields expected added consumer rent given in Proposition 2.2.

Derivation of the Optimal Investment for our Parameterization The profit function of firm i (i={1, 2, 3}) with an endowment B=100 at the market stage in each of the 30 rounds is given by:

$$\pi_i(r_i,r_j,r_k)=(p-c^L)(1+\theta)F(r_i)(1-F(r_j))(1-F(r_k))-(1-\sigma)r_i+B$$

Taking the equilibrium price p=c^H, $F(r_i)=\frac{1}{10}r_i^{0.5}$, T=2, $\sigma=0.5$ and $\theta=1$ yield the following first order conditions (FOC):

FOC general:

$$\frac{\partial\pi_i(r_i,r_j,r_k)}{\partial r_i}=\frac{\frac{1}{20}(c^H-c^L)(1+\theta)(1-\frac{1}{10}r_j^{0.5})(1-\frac{1}{10}r_k^{0.5})}{r_i^{0.5}}-(1-\sigma)=0$$

FOC *NO* ($\sigma=0,\ \theta=0$):

$$\frac{\partial\pi_i(r_i,r_j,r_k)}{\partial r_i}=\frac{\frac{1}{20}(c^H-c^L)(1-\frac{1}{10}r_j^{0.5})(1-\frac{1}{10}r_k^{0.5})}{r_i^{0.5}}-1=0.$$

FOC *SUB* ($\sigma=0.5,\ \theta=0$):

$$\frac{\partial\pi_i(r_i,r_j,r_k)}{\partial r_i}=\frac{\frac{1}{20}(c^H-c^L)(1-\frac{1}{10}r_j^{0.5})(1-\frac{1}{10}r_k^{0.5})}{r_i^{0.5}}-\frac{1}{2}=0.$$

FOC *PAT* ($\sigma=0,\ \theta=1$):

$$\frac{\partial\pi_i(r_i,r_j,r_k)}{\partial r_i}=\frac{\frac{1}{10}(c^H-c^L)(1-\frac{1}{10}r_j^{0.5})(1-\frac{1}{10}r_k^{0.5})}{r_i^{0.5}}-1=0.$$

Solving these equation systems for each treatment leads to the equilibrium investments presented in Table 2.

SOC general case:

$$\frac{\partial^2 \pi_i(r_i, r_j, r_k)}{\partial r_i^2} = -\frac{\frac{1}{40}(c^H - c^L)(1+\theta)(1 - \frac{1}{10}r_j^{0.5})(1 - \frac{1}{10}r_k^{0.5})}{r_i^{1.5}} < 0.$$

For the given parameters SOC is always negative.

Added Welfare In general, expected added welfare through R&D is given by

$$W^e(r) = (1 - \prod_{i=1}^{n}[1 - F(r_i)])T\Delta c - \sum_{i=1}^{n} r_i,$$

where Δc gives the increase in welfare if at least one firm succeeds in R&D,[51] which occurs with probability $1 - \prod_{i=1}^{n}[1 - F(r_i)]$, and $\sum_{i=1}^{n} r_i$ gives the total R&D investment costs in the industry.

Expected added welfare for symmetric R&D investment levels $r_i{=}r$ is given by

$$W^e(r) = (1 - [1 - F(r)]^n)T\Delta c - nr.$$

Comparative Statics of the Optimal Investment The optimal investment is characterized by the first order condition:

$$\frac{\partial \pi_i(r_i, r_j, r_k)}{\partial r_i} = Q(c^H - c^L)(1+\theta)f(r_i)(1 - F(r_j))(1 - F(r_k)) - (1 - \sigma) = 0$$

With the implicit function theorem $\left(\frac{dr_i}{dr_j} = -\frac{\frac{\partial^2 \pi_i(r_i,r_j,r_k)}{\partial r_i r_j}}{\frac{\partial^2 \pi_i(r_i,r_j,r_k)}{\partial r_i^2}}\right)$ we can show that the firm's investment decreases with an increase in the rival's investment:

$$\begin{aligned}
\frac{\partial^2 \pi_i(r_i, r_j, r_k)}{\partial r_i r_j} &= -Q(c^H - c^L)(1+\theta)f(r_i)f(r_j)(1 - F(r_k)) \\
\frac{\partial^2 \pi_i(r_i, r_j, r_k)}{\partial r_i^2} &= Q(c^H - c^L)(1+\theta)f'(r_i)(1 - F(r_j))(1 - F(r_k)) \\
\frac{dr_i}{dr_j} &= \frac{f(r_i)f(r_j)}{f'(r_i)(1 - F(r_j))} < 0.
\end{aligned}$$

A.2 Additional Experimental Results

Mark-ups of the firms are defined as *price − costs* and represent the firm's incentive to innovate. Recall that theoretically predicted mark-ups if there are zero, one, two and three innovations are 0, 399, 0, and 0 points in the first market; 0, 0, 0, and 0 in the second

[51] The additional welfare of a lower market price if at least one firm's innovation is successful compared to the initial higher price is given by $(\bar{p} - c^L) - (\bar{p} - c^H) = c^H - c^L \equiv \Delta c$.

market for *NO* and *SUB* due to imitation, and 0, 399, 0, and 0 in the second market for *PAT*. Table 15 shows that mark-ups deviate to some extent from Nash predictions. Hence, observed mark-ups are higher when zero-mark-ups are predicted if there are no, two, or three low cost firms and slightly lower when mark-ups of 399 points are predicted if there is a sole low cost firm. Moreover, deviations appear to be systematic. First, observed average mark-ups are always larger in the first than the second market period for a given cost structure and treatment, except when there is only one low cost firm in *PAT*.[52] Second, mark-ups rank in a specific ascending order of cost structures: Three low cost firms achieve somewhat higher mark-ups than three high cost firms, and two low cost firms have somewhat higher mark-ups than three low and high cost firms, i.e., it holds $zero < three < two < one$ low cost firms for a given market period and treatment. Table 15 shows that in terms of providing incentives to invest in R&D *PAT* is not only the best policy for a sole innovating firm as the observed (theoretically predicted) sum of mark-ups of both periods amounts to 788.87 (798) compared to 407.76 and 380.26 (both 399) in *NO* and *SUB*, but furthermore it also yields the highest sum of mark-ups for all other cost structures (zero, two and three). In *SUB* mark-ups over both periods are lowest. Note that here incentives to innovate refer to a 'pure' mark-up effect (and target solely at the revenue side of firms) neglecting incentives which arise from a reduction of investment costs.

A.3 Figures

Figures 10 to 12 give average lowest prices for each cost structure in the 1st and 2nd Bertrand markets for each round. In case there is no entry there was no group consisting of that special number of low cost firms in that specific round. Note that the number of low cost firms only refers to the cost structure in the first market period (i.e., it refers to the number of initially successfully innovating firms). The labeling specifies different cost structures after the investment stage and gives prices for both periods of the Bertrand market.

[52] This result is driven by the higher price setting in the first market.

Figure 7: Individual investment behavior in *NO*

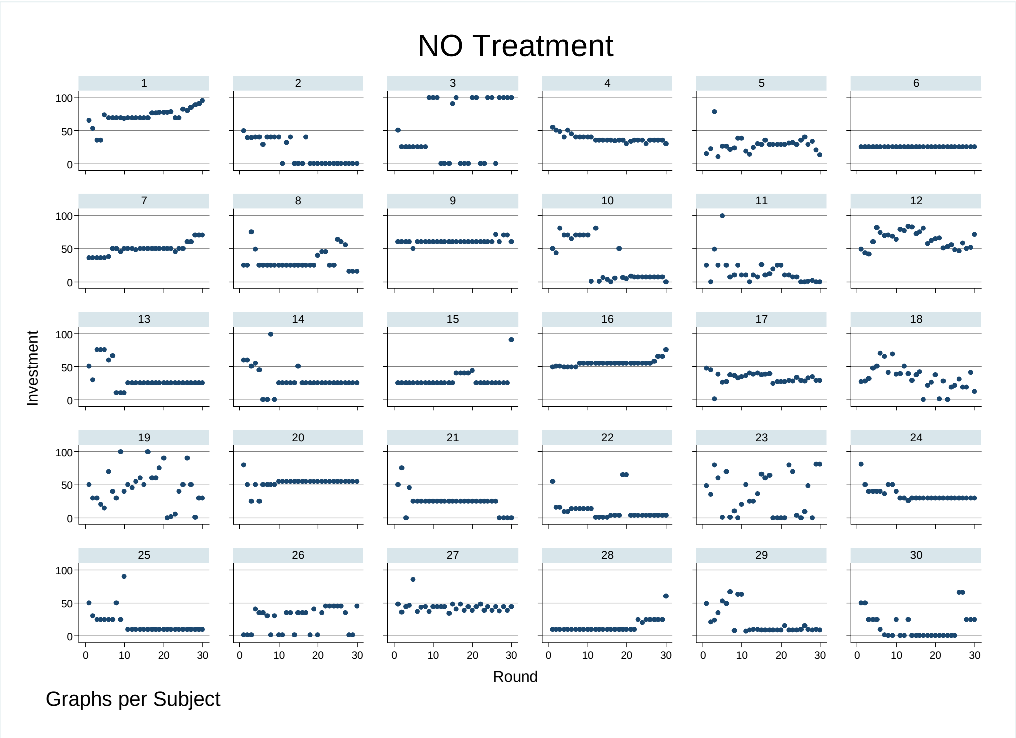


Figure 8: Individual investment behavior in *SUB*

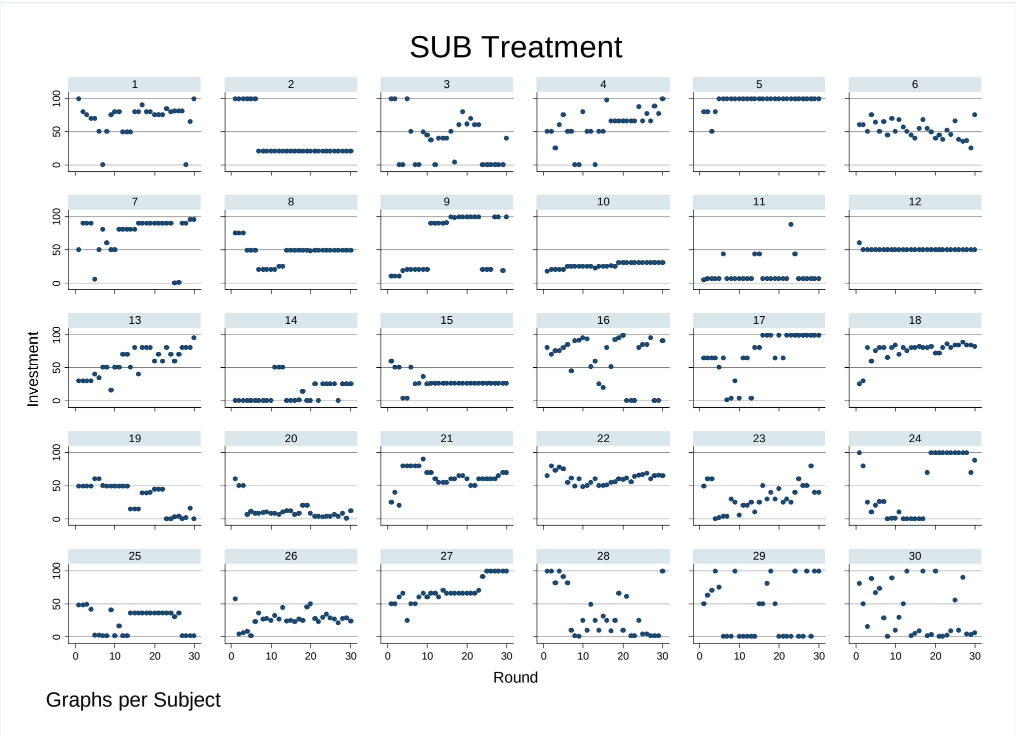


Figure 9: Individual investment behavior in *PAT*

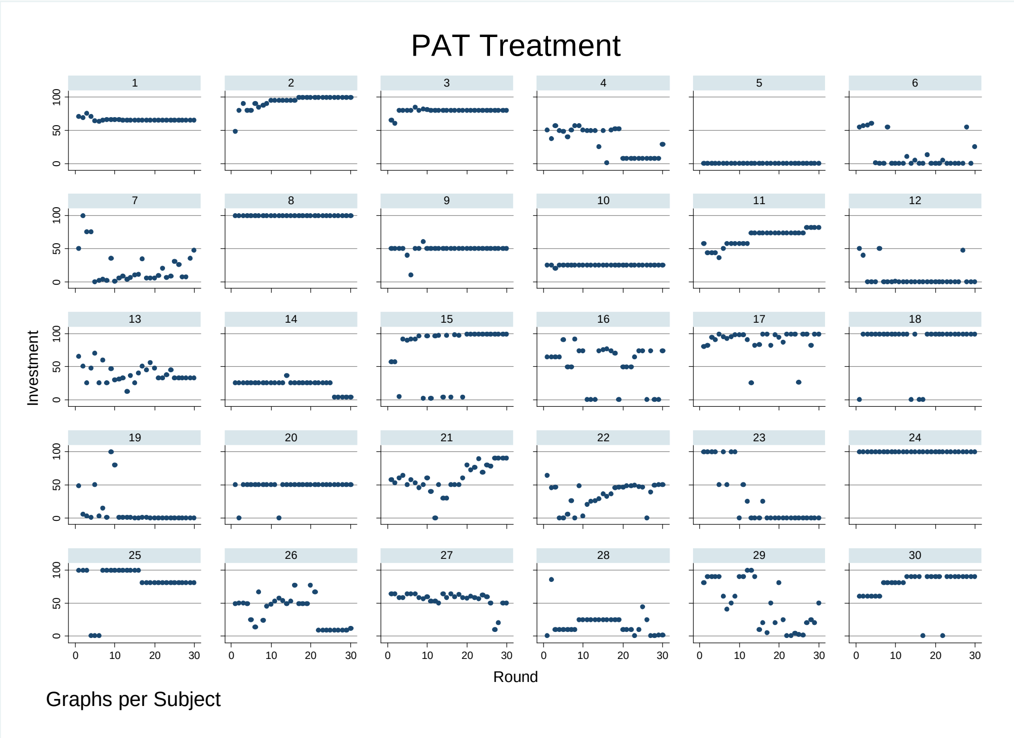


Figure 10: Average lowest prices for each cost structure over rounds in *NO*

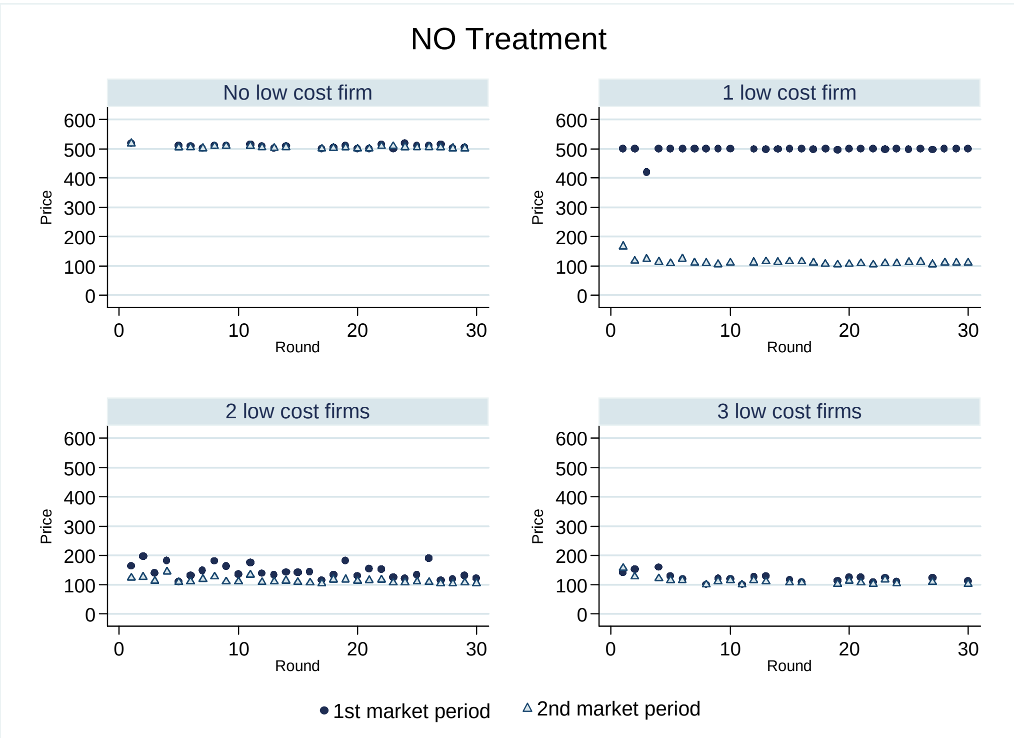


Figure 11: Average lowest prices for each cost structure over rounds in *SUB*

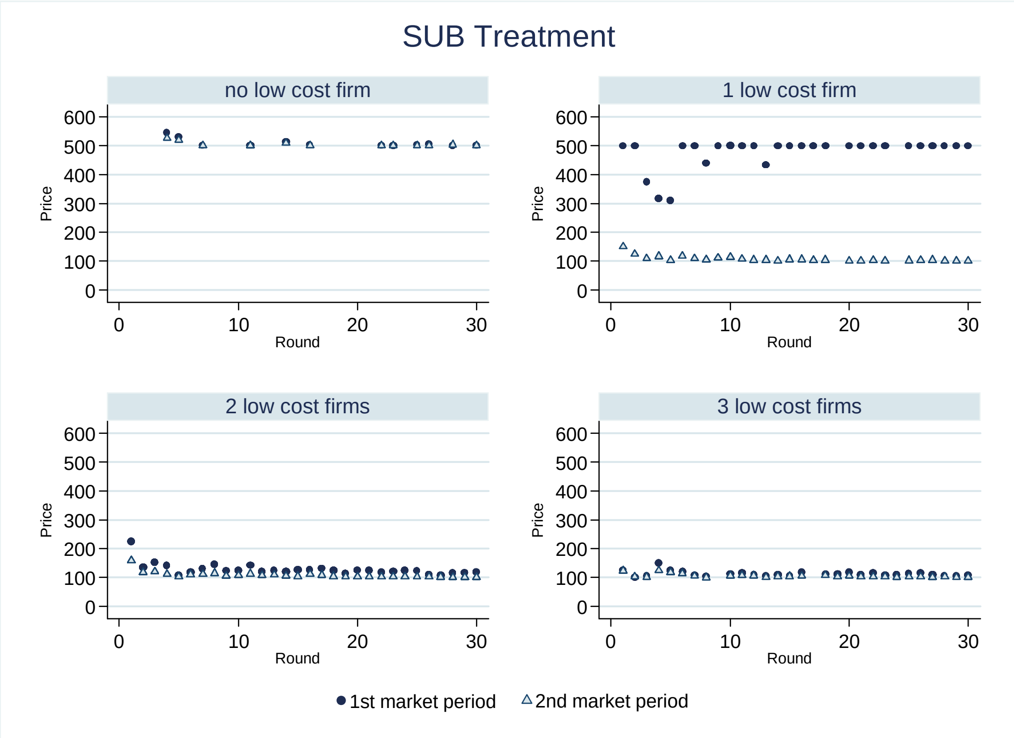
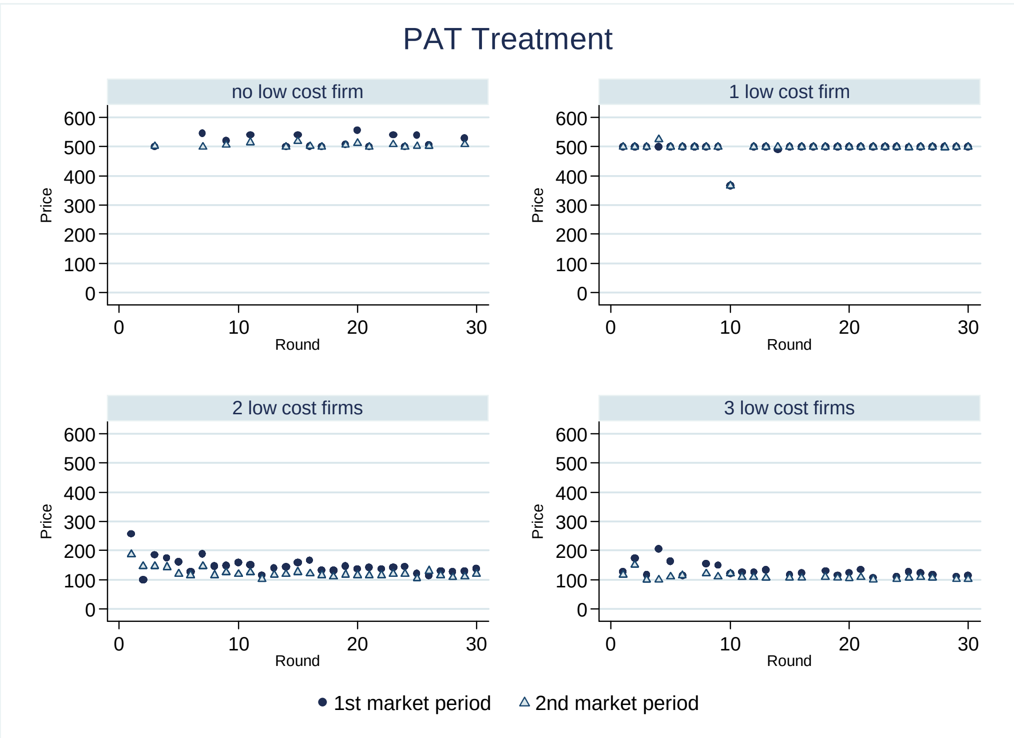


Figure 12: Average lowest prices for each cost structure over rounds in *PAT*



A.4 Tables

Table 12: Discrete symmetric and asymmetric Nash equilibrium investment levels

NO			*SUB*			*PAT*		
r_i	r_j	r_k	r_i	r_j	r_k	r_i	r_j	r_k
0	0	99	0	0	99	0	0	99
20	25	30	**37**	**37**	**37**	**37**	**37**	**37**
20	26	29						
20	27	28						
21	24	30						
21	25	29						
21	26	28						
21	27	27						
22	23	30						
22	24	29						
22	25	28						
22	26	27						
23	23	29						
23	24	28						
23	25	27						
23	26	26						
24	24	27						
24	25	26						
25	**25**	**25**						

$\Delta c = 399$ is taken for the computation of equilibria (compare Footnote 24).

Table 13: OLS regression on investment with *CR1* as base category

NO	44.084***	(5.057)
SUB	57.408***	(3.272)
PAT	74.744***	(0.748)
$CR0_{t-1} \times NO$	-15.823***	(2.870)
$CR0_{t-1} \times SUB$	-25.626***	(1.862)
$CR0_{t-1} \times PAT$	-46.842***	(4.337)
$CR2_{t-1} \times NO$	-3.872*	(2.169)
$CR2_{t-1} \times SUB$	-3.171	(2.543)
$CR2_{t-1} \times PAT$	-8.722***	(2.585)
$CR3_{t-1} \times NO$	-9.592**	(4.391)
$CR3_{t-1} \times SUB$	-1.834	(2.590)
$CR3_{t-1} \times PAT$	-15.486***	(1.304)
R^2	0.218	
N	2610	
No. of clusters	15	

Standard errors in parentheses are corrected for matching group clusters. Cost reduction dummy variable *CR1* is dropped as base category. As we drop the constant in the estimated models, the reported R^2 is taken from the(analogous) model (2) as presented in Table 14. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 14: OLS regression results with SUB as base category

Investment	Model (1)		Model (2)		Model (3)	
NO	-3.521	(3.336)	-3.521	(3.340)	-8.171**	(2.855)
PAT	-3.881	(4.222)	-3.881	(4.227)	-7.511*	(4.008)
Constant	31.783***	(2.086)	31.783***	(2.088)	34.840***	(1.626)
$CR_{t-1} \times NO$	-12.163***	(3.813)			-11.994***	(3.709)
$CR_{t-1} \times PAT$	14.144**	(4.967)			14.316**	(4.915)
CR_{t-1}	23.341***	(3.096)			23.088***	(2.983)
$CR1_{t-1} \times NO$			-9.803**	(3.422)		
$CR1_{t-1} \times PAT$			21.216***	(4.720)		
$CR1_{t-1}$			25.626***	(1.862)		
$CR2_{t-1} \times NO$			-10.505**	(4.472)		
$CR2_{t-1} \times PAT$			15.665***	(4.660)		
$CR2_{t-1}$			22.455***	(3.652)		
$CR3_{t-1} \times NO$			-17.561***	(4.201)		
$CR3_{t-1} \times PAT$			7.564	(5.153)		
$CR3_{t-1}$			23.792***	(3.160)		
round1_15$\times NO$					9.393***	(2.441)
round1_15$\times PAT$					7.290**	(2.656)
round1_15				-6.004***	(1.917)	
R^2	0.211		0.218		0.215	
N	2610		2610		2610	
No. of clusters	15		15		15	

Standard errors are given in parentheses and are corrected for matching group clusters.
Treatment dummy variable SUB is dropped as base category. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 15: Average mark-ups in the Bertrand markets

		Number of innovating firms			
Bertrand markets	Treatment	Zero	One	Two	Three
1st period	NO	8.37	394.37	46.13	24.14
	SUB	7.36	373.00	27.77	12.69
	PAT	19.29	393.88	49.20	31.36
2nd period	NO	4.66	13.39	14.23	13.55
	SUB	4.93	7.26	8.77	6.12
	PAT	4.53	394.99	24.48	11.13
Both periods	NO	13.03	407.76	60.36	37.69
	SUB	12.29	380.26	36.54	18.81
	PAT	23.82	788.87	73.68	42.49

The number of innovating firms indicates the successfully innovating firms after the investment stage i.e., low cost firms in the first market period, but does not refer to imitating firms in the second market period.

A.5 Instructions (Translation from German)

Welcome and thank you very much for participating in this experiment. You receive 2.50 € for participating. Depending on your and other participants' decisions you can earn additional money. You collect points during the experiment with **300 points equaling 1 €**. At the end of the experiment your accumulated points will be converted into €and together with the 2.50 € paid out to you in cash. Payoffs remain *anonymous*. During the whole experiment, starting now, communication with other participants is strictly forbidden. If you have a question, please raise your hand. An experimenter will come to your place and answer your questions.

The Experiment

The experiment consists of **30 rounds**. At the beginning of *each* round all participants are randomly divided into groups of 3 participants, i.e., the composition of your group changes in each round. In the following we refer to the 3 participants of your group as firm 1, 2, and 3. Your firm number is randomly drawn anew in each round. You do not interact with other groups in a respective round. Your identity is not revealed at any time before, during or after the experiment.
At the beginning of *each* round each participant receives an **endowment of 100 points** which is credited your personal account of points.
Each round consists of 2 phases ("phase 1" and "phase 2"). In addition phase 2 consists of two sub-phases ("phase 2A" and "phase 2B"). You make three decisions in each round, one in phase 1 and one in each of the phases 2A and 2B.

Phase 1 – 1st Decision

In phase 1 you and the two other firms in your group can make an investment. Each firm can influence the level of its costs in the *current round* by its investment. You can have either *high* or *low costs*. You invest by choosing an amount of points (integer) between 0 and 99 (0, 1, 2, . . . , 98, 99). Only you know your own investment (chosen points), it cannot be observed by any other firm. The same applies to the other firms.

PAT and NO:
Your investment induces **investment costs; they are equal to your investment (= chosen points) and will be subtracted from your endowment of 100 points.**

SUB:
Your investment induces **investment costs; they are equal to half of your investment (= chosen points) and will be subtracted from your endowment of 100 points.**

Your investment level determines the **probability** of having costs of **100 points** ("low costs") or of **500 points** ("high costs") in the *current* round. The higher your investment, the higher the probability that you have low costs (100 points). The same applies to the

two other firms in your group.[53]
After you and the other two firms in your group made their investment decision, the computer separately draws a random number for *each* firm. The number is in the range of 0.1 and 100 whereby all numbers (0.1, 0.2, ..., 99.8, 99.9, 100) have an equal chance to be drawn.
Two alternatives arise:

1. **Your random number is *smaller than or equal* to your probability of obtaining costs of 100 points:** In this case your costs amount to 100 points.

2. **Your random number is *higher than* your probability of obtaining costs of 100 points:** In this case your costs amount to 500 points.

The same applies to both other firms in your group. Thus, your costs only depend on your own investment level which yields the probability of obtaining certain costs and chance. Four different situations can arise: Either none, 1, 2 or all 3 firms of your group have low costs of 100 points (the rest of the firms in the group faces high costs of 500 points).

Phase 2A – 2nd Decision

At the beginning of phase 2A each firm within your group gets to know the costs of *all three* firms.
Each firm in your group is asked to choose a price between your own costs in phase 2A and 1000, i.e., a price either between <u>100</u>, 101, 102, ... 999, 1000, if you have low costs or between <u>500</u>, 501, 502, .., 999, 1000, if you have high costs. Each firm only knows its own price and cannot observe the prices of the other two firms.

After all firms made their decisions, the computer identifies the *lowest* price within your group which all three firms get to know. There are three possibilities for your group in phase 2A with the according profits:

1. **<u>One</u> firm in your group has chosen the lowest price:**
   The profit in points of the firm with the lowest price in phase 2A is calculated by *subtracting the costs of this firm in phase 2A from its chosen price.* Both firms with the higher prices receive *nothing* (0 points) in phase 2A, independent of their prices and costs in phase 2A.

2. **<u>Two</u> firms in your group have chosen the same lowest price:**
   The profit in points of each firm with the same lowest price in phase 2A is calculated by *subtracting the costs from the chosen price and <u>dividing the result by two</u>.* The firm with the higher price receives *nothing* (0 points) in phase 2A, independent of its price and costs in phase 2A.

[53]All participants received a table containing all possible investment levels, the according investment costs, and the resulting probabilities of obtaining costs of 100 or 500 points. The probabilities are calculated by the formula $\sqrt{i/100}$, i stands for the investment of one firm.

3. **All three firms in your group have chosen the same price:**
   The profit in points of each firm in phase 2A is calculated by *subtracting the costs from the chosen price and dividing the result by three*.

If you have not chosen the lowest price of your group in phase 2A, you will not bear any costs. At the end of phase 2A your profit, which can either be positive or zero, is credited your personal account of points.

Phase 2B – 3rd Decision

PAT:
The 3^{rd} decision is identical to the 2^{nd} decision. **Each firm's costs have not changed compared to phase 2A.**

NO and SUB:
The 3^{rd} decision just differs slightly from the 2^{nd} decision in phase 2A. The decision procedure and the computation of profits in phase 2B are the same as in phase 2A. But compared to phase 2A there is an important difference: **In phase 2B the costs of all firms in one group are the same. The equal cost level in phase 2B corresponds to the lowest costs within the group in phase 2A.** The costs in phase 2B which are identical for all three firms in your group are announced within your group before you have to choose your price.

After a round (consisting of phase 1, phase 2A, and phase 2B) is finished you are informed again about your decisions and the results of this round. Afterwards the next round starts.

Profit per Round

	Profit per round =
Phase 1	endowment per round – investment costs in phase 1
Phase 2	+ profit in phase 2A
	+ profit in phase 2B

Table 16: Probabilites and costs for *NO* and *PAT*

Your investment (chosen points)	Your investment costs Your investment costs	Probability of getting costs of 100 points in %	Probability of getting costs of 500 points in %
0	0	0,0	100,0
1	1	10,0	90,0
2	2	14,1	85,9
3	3	17,3	82,7
4	4	20,0	80,0
5	5	22,4	77,6
6	6	24,5	75,5
7	7	26,5	73,5
8	8	28,3	71,7
9	9	30,0	70,0
10	10	31,6	68,4
11	11	33,2	66,8
12	12	34,6	65,4
13	13	36,1	63,9
14	14	37,4	62,6
15	15	38,7	61,3
16	16	40,0	60,0
17	17	41,2	58,8
18	18	42,4	57,6
19	19	43,6	56,4
20	20	44,7	55,3
21	21	45,8	54,2
22	22	46,9	53,1
23	23	48,0	52,0
24	24	49,0	51,0
25	25	50,0	50,0
⋮	⋮	⋮	⋮
75	75	86,6	13,4
76	76	87,2	12,8
77	77	87,7	12,3
78	78	88,3	11,7
79	79	88,9	11,1
80	80	89,4	10,6
81	81	90,0	10,0
82	82	90,6	9,4
83	83	91,1	8,9
84	84	91,7	8,3
85	85	92,2	7,8
86	86	92,7	7,3
87	87	93,3	6,7
88	88	93,8	6,2
89	89	94,3	5,7
90	90	94,9	5,1
91	91	95,4	4,6
92	92	95,9	4,1
93	93	96,4	3,6
94	94	97,0	3,0
95	95	97,5	2,5
96	96	98,0	2,0
97	97	98,5	1,5
98	98	99,0	1,0
99	99	99,5	0,5

The table given to the subjects included all integer numbers between 0 and 99 and in *SUB* investment costs are halved.

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Chapter 4

Determinants of Successful Cooperation in a Face-to-Face Social Dilemma

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1 Introduction

The well known prisoner's dilemma game has become the classic economic example to demonstrate non-cooperative behavior: Two contestants face a "dilemma" in which, independent of the other's action, each player is better off by defection than by cooperation. But, the outcome obtained when both defect is worse for each player than the outcome they would have obtained if both had cooperated. Thus, self-interested behavior does not unequivocally lead to a globally optimal solution. Two players who both pursue rational self-interest may end up worse off than if both act contrary to rational self-interest.

This paper uses data from the television show "Golden Balls" which gives us the opportunity to analyze cooperative behavior in an environment of high stakes and face-to-face communication between players as well as players' behavior in the pre-play. Players are not only allowed to talk to each other, but they have the possibility to play with each other, and thereby build a reputation of being trustworthy or being a liar.

The show consists of three rounds, the first two are pre-play and in the third two contestants play a prisoner's dilemma with defection being a weakly dominant strategy. Starting with four contestants, each round every player is randomly assigned a certain cash value. These values are partly common knowledge and partly private information for the respective player. Then players make truthful or untruthful statements about their values. At the end of each round, each player has to cast a vote against one of the other players. The one who receives the majority of votes has to leave the show empty-handed and her values are taken out of the game. Thus, the selection procedure determines the two finalists and the stake size at the same time and does not involve any effort provision by the contestants. The two final players decide about the division of the stakes via playing a prisoner's dilemma. Immediately before the dilemma is played, they can discuss their intentions with respect to their final decision.

Our contribution consists not only of (i) the analysis of cooperative behavior in the presence of high stakes and face-to-face communication, but also of (ii) the analysis of the players' behavior in the pre-play, especially their voting decisions with respect to its influence on the outcome of the prisoner's dilemma. Concerning cooperative behavior, we observe a unilateral cooperation rate of 55% and a mutual cooperation rate of 33%. Our analysis shows a negative correlation between the stake size and the cooperation rate with a substantial decline around the level of £500. In games with stakes below that value, the unilateral cooperation rate even increases to 74%, and the mutual cooperation rate to 56%. Further, we can show that player's expectation about the stake size matters. If the jackpot is lower than expected, the players are more likely to cooperate. With respect to communication, certain words and gestures are more important than others. Mutually promising each other to cooperate and shaking hands on it increases the cooperation rate, whereas shaking hands without a promise leads to a decline. Apart from those effects, demographic characteristics, such as age and place of residence, matter.
The analysis of the contestants' behavior in the pre-play shows that players make their voting decision dependent on objective criteria such as their opponent's monetary contribution to the stake size, but also on subjective criteria such as the player's trustworthiness and race. In addition, we observe that the weight given to objective and subjective criteria changes between the first and the second voting decision. In the second round, apart from stake size, player's trustworthiness seems to be more important than player's demographics. Further, we show that there is a strong link between the two rounds of pre-prisoner's dilemma play and the player's decision on cooperation. For instance, we find that whether a player lied about her stakes in the pre-play has a significant effect on the cooperation rate.

While writing the first draft of this paper, published in July 2010, it came to our attention that van den Assem, van Dolder, and Thaler (2010) are independently analyzing data from "Golden Balls". They came out first with a working paper in April 2010. The only overlap of both studies is the analysis of unilateral cooperation, focussing on the final round. As we mentioned, we also extensively analyze the pre-play and link it to the mutual and unilateral decision outcome of the prisoner's dilemma game. We additionally include variables describing communication, e.g., whether players shake hands or promise each other to cooperate, or lied before. Because of the independent construction of the data set, both studies differ with regard to the definition and modeling of variables. Therefore our analysis and results differ in various aspects.

The structure of the paper is organized as follows. We start with a brief review of the related literature, Section 2, followed by a description of the game show and data set, Section 3. In Section 4 we explain the strategic considerations of the players and motivate our analysis. Sections 5 and 6 represent the main part of the paper, including the empirical analysis and obtained results on cooperative behavior in the prisoner's dilemma as well as contestants' voting behavior in the pre-play. Section 7 concludes.

2 Literature Review

In this section, we first review studies that are closely related to our paper in terms of using television show data and/or in terms of considering a prisoner's dilemma with defection being the weakly dominant strategy. Secondly, we present studies analyzing the effect of stake-size, anonymity, communication, and gestures on cooperative behavior in social dilemma games. Finally, we give a brief overview of results about lying and discrimination in voting decisions.

Television Game Shows and Weak Prisoner's Dilemma

Related studies that use television game show data are List (2006), Oberholzer-Gee, Waldfogel, and White (2010), and Belot, Bhaskar, and van de Ven (2010). The first two analyze "Friend or Foe", a US game show, and the latter analyzes "Will (s)he share or not?", a show from the Netherlands. In both shows pairs of players build a jackpot by answering trivia questions together. The teams have to decide about the division of their accumulated jackpot by playing a prisoner's dilemma with weakly dominant strategies. In contrast, in "Golden Balls" stakes are built by a random process and the two final players are selected on the basis of a two-round voting procedure. In addition, "Golden Balls" provides the opportunity to analyze a game with very high stakes, i.e., the average jackpot is more than three times as high as the average jackpot in "Friend or Foe" and its median value is more than three times the median in “Will (s)he share or not”. All three studies find a very high cooperation rate (around 50%), but only Belot, Bhaskar, and van de Ven (2010) find an effect of the stake size.

Little empirical work has been done on cooperation in prisoner’s dilemma games in which defection is a weakly dominant strategy.[1] Ortmann and Tichy (1999) analyze the game with respect to gender differences. They find an overall cooperation rate of 46%, and that females cooperate more frequently than males. Studies related to the idea of Rapoport (1988) show that the cooperation rate is higher in a prisoner’s dilemma with weakly dominant strategies than in one with strictly dominant strategies.[2]

Stake Size, Anonymity, and Communication

The effect of the stake size on cooperation rates in dilemma games is widely debated and no clear answer has been found so far. Some experiments show that there is no significant effect, whereas others suggest that the cooperation or contribution rate decreases with the stake size (e.g., Camerer and Hogarth (1999)).

Compared to experiments in the laboratory, contestants in “Golden Balls” do not anonymously play the prisoner’s dilemma and are allowed to communicate with each other before choosing their action. The relevance of anonymity in dictator games is shown by Hoffman, McCabe, Shachat, and Smith (1994). If people feel observed by the experimenters they are more altruistic than in a double-blind setting. In addition, Rege and Telle (2004) showed that the framing of the instructions of the game may raise the cooperation or contribution rate. Since the players in the game under consideration are filmed and play in front of a large television audience, we can expect a similar effect, i.e., a positive effect on cooperation. The cooperation rate we observe is, however, not much different to the rate reported by Ortmann and Tichy (1999), which might suggest that the effect of the audience is not as strong as expected.

In addition, experimental studies have shown that communication increases the cooperation rate significantly (for surveys see Sally (1995), Ledyard (1995)), al-

[1] There is a vast experimental literature on prisoner’s dilemma games in which defection is a strictly dominant strategy. There the observed cooperation rate varies between 30-40% (see e.g., Shafir and Tversky (1992)).

[2] Rapoport (1988) finds that the cooperation rate in a prisoner’s dilemma without fear ($\widehat{=}$ payoff difference between the mutual defector’s and unilateral cooperator’s payoff) is higher than in one with fear and predicts a cooperation rate of 50% for a no-fear dilemma that corresponds to the game analyzed in this paper. The prediction is independent of the stake size. Rapoport’s findings are supported in experiments conducted by Ahn, Ostrom, Schmidt, Shupp, and Walker (2001) as well as Ahn, Ostrom, Schmidt, and Walker (2003).

though from a theoretical point of view in a prisoner's dilemma communication is cheap talk (see e.g., Crawford (1998), Farrell and Rabin (1996)).[3] Bohnet and Frey (1999) analyze the effects of face-to-face communication on cooperative behavior and show that it is very effective, i.e., they observe an increase in the unilateral cooperation rate up to 78%.

Apart from the effects of face-to-face communication, gestures such as a smile might have an impact on cooperation. Scharlemann, Eckel, Kacelnik, and Wilson (2001) investigate the impact of a smiling face on people's behavior in a one-shot trust game. They find that subjects are significantly more likely to trust smiling counterparts. Manzini, Sadrieh, and Vriend (2009) address this issue in the minimum effort game and test whether people's propensity to choose high effort is increased if subjects can send a "smile" to the other player instead of pressing an ordinary "ready to play" button. They find that this simple device helps players to coordinate on a higher effort even though players are not able to see or to talk to each other.

Furthermore, studies have shown that the effectiveness of communication differs by the words that are used, for instance, when making a promise. Vanberg (2008) finds that people have a preference for keeping a promise and are not driven by concerns about their expected payoff. Ellingsen and Johannesson (2004) propose that people have a preference for keeping their word per se. In contrast, Charness and Dufwenberg (2006) develop the idea that people keep promises because of guilt aversion.[4] Belot, Bhaskar, and van de Ven (2010) investigate the effect of voluntary vs. elicited promises and find that players are roughly 50% more likely to cooperate if they made a voluntary promise.

Lying and Voting Behavior

As already mentioned above, guilt is experienced by subjects if they do not keep a promise or in other words lied about their intention which strategy they plan to play. Gneezy (2005) uses a cheap talk sender-receiver game and shows that people's evaluation of whether to lie or not in a situation depends on the consequences of the lie in terms of payoffs. Thereby not only gains achievable through lying are considered but also possible losses that might occur to the other players. The fraction of liars is largest if the resulting gains are high and the costs, i.e., losses for the other

[3] In laboratory experiments free-form written communication is often used instead of face-to-face verbal communication to be able to disentangle the effect of facial expressions from the bare content of communication. Roth (1995) provides a survey of bargaining experiments in which the effect of face-to-face communication is tested. The results suggest that face-to-face communication increases the chance of reaching an agreement even further than free-form messaging.

[4] In related work, Miettinen and Suetens (2008) show that players feel most guilty if they communicated their intention to cooperate, but then defect while the opponent cooperates. Charness and Dufwenberg (2010), however, show that providing subjects merely the possibility of communication by sending the word promise or not has almost no positive effect on the cooperation rate in a trust game.

players, are low. If players have the opportunity to costly punish the other subjects for playing selfishly, they punish much more often if the selfish action followed a deceptive message (Brandts and Charness, 2003). Another approach to analyzing lying is made by Fischbacher and Heusi (2008) who try to figure out under which circumstances people lie. They find that the distribution of truthful, partially truthful and untruthful people is more or less the same independent of the stake size, the consequences of lying, learning, and the degree of anonymity.

Finally, the partner selection process taking place during the two pre-play rounds in "Golden Balls" draws our attention to the literature on discrimination. There exists a vast economic as well as psychological literature on racial and gender discrimination usually with the focus on the labor market (for a comprehensive survey see Altonji and Blank (1999)). Using the data of the US television game show "The Weakest Link", Levitt (2004) and Anonovics, Arcidiacono, and Walsh (2005) test taste-based and information-based theories of discrimination, determining whether contestants discriminate on the basis of gender, age, race, and skill level. While Levitt (2004) finds some patterns consistent with information-based discrimination and taste-based discrimination against older players, Anonovics, Arcidiacono, and Walsh (2005) reveal taste-based discrimination by women against men.

To summarize, there are various reasons to observe a different cooperation rate than the one predicted by game theory and the one observed in laboratory experiments without communication, high stakes, and endogenous partner selection.

3 Game Show and Data Set

In this section we describe in detail the course of events in the game show (Section 3.1) and the data set (Section 3.2).

3.1 Structure of the Game Show

The game show "Golden Balls" consists of three rounds of play with the final round being divided into two phases.

Round 1 The game show starts with four players[5], usually two women and two men, who are briefly introduced by the show host, i.e., the players provide some information about themselves including their names, occupation and place of resi-

[5]Endemol UK ensured us that the four players do not know each other before the show, and enter and leave the television studio separately (they cannot make any further arrangements after the show).

dence. Then the first round starts: 16 golden balls are mixed, twelve of them have written a cash amount (in £) inside and four have written the word "killer" inside. Killer balls are the worst for the players, because these may damage the jackpot in the final round. The balls containing a cash value are drawn from a lottery of 100 golden balls with a minimum ball value of £10 and a maximum ball value of £75,000.[6] Each player arranges the closed golden balls in two rows of two balls in front of herself. The two balls on the front row are opened by each player, and the revealed cash values or number of killers is common knowledge to each player. The content of the remaining two balls is private information to each player, i.e., the players are allowed to secretly look inside but then have to close the balls again. Afterwards the show host asks each player to state what is inside her hidden balls. The order in which players are asked for their statements is exogenously determined by the show host. Some time for discussion follows, in which the players express their distrust about each other's statements. The discussion ends with each player secretly casting a vote against one of the other players. On the basis of the votes, a player is eliminated from the show.[7] After the player who has to leave is determined, all players open their hidden back row balls and thereby reveal whether they stated the truth or not. The four balls of the leaving player are out of the game, while the remaining twelve are carried over to round 2.

Round 2 At the beginning of the second round, two new cash balls are drawn from the lottery and one killer ball is added. These three new balls are mixed with the remaining twelve from round 1, and are equally distributed to the three players at random. Hence, there are at most five killers among the 15 balls. Again the closed balls are arranged in two rows by each player, i.e., two balls are on the front and three balls are on the back row. As in round 1 the two balls on the front row are opened and are common knowledge, while the three balls on the back are private information. This time the players determine themselves the order of making statements about the content of their back row balls. Like in the first round, the players then get some time for discussion and afterwards secretly choose a player they want to vote off. After the player to leave has been determined all ball values are revealed, the five balls of the leaving player are out of the game, and the final two players are identified.

Final Round The 10 balls from round 2 are carried over to the final round and one last killer ball is added. The maximal amount the players can gain is the sum of

[6] Players have only limited information about the lottery, i.e., they only know that there may be doubles and they know the margins of the distribution. But they do not know the distribution of the remaining 98 balls.

[7] The player who receives the highest number of votes has to leave the show. In case of a tie the players having received no vote can decide which player has to leave. If all players received one vote each, players discuss openly which player has to leave. If players do not reach a conclusion, ties are broken arbitrarily. In round 2 it is proceeded in the same way.

the highest five cash values out of the 11 balls. This amount is called the potential jackpot and its size is announced by the show host.
In the *first phase* of the final round the two players successively select five of the 11 mixed and closed balls, and these five values build the jackpot. The player who brought the highest amount of money from round 2 to the final round starts to select one of the balls to "bin", i.e., to be taken out of the game, and then chooses one ball to "win". The balls are not opened until they have been chosen. Then it is the other player's turn and vice versa until five balls have been selected for the jackpot. If a player chooses a killer ball for the jackpot the accumulated amount up to that point is reduced to one-tenth of the original value.
In the *second phase* of the final round the players play a prisoner's dilemma in which defection is a weakly dominant strategy (see Table 1).[8]

Table 1: Weak prisoner's dilemma

	Split (C)	Steal (D)
Split (C)	$\frac{1}{2}J$, $\frac{1}{2}J$	0 , J
Steal (D)	J , 0	0 , 0

C $\hat{=}$ Cooperation, D $\hat{=}$ Defection

Such a prisoner's dilemma has three pure-strategy Nash equilibria, namely (steal, split), (steal, steal), and (split, steal).[9] Thus, each player has an incentive to defect, because she is never monetarily worse off when doing so. Before the players have to decide which strategy to play, they get some additional time, roughly 30 seconds, to discuss with each other what they are going to do.
The dilemma game is played as follows: Each player is assigned two balls, one with the word "steal" and one with the word "split" inside. Then both players choose one of the balls and open it simultaneously. If both players chose the split ball, the jackpot (J) is divided equally between the two players. If one player chooses steal and the other chooses split, the former gets the whole jackpot and the latter receives nothing. If both chose steal, both get nothing.

[8]The show host explains the different outcomes of the game in each episode with the same neutral words (for the exact wording see Appendix A.1).
[9]Two of the resulting Nash equilibria involve one player to cooperate. Applying the method of iterated elimination of weakly dominant strategies, however, leaves only the (steal, steal) equilibrium, which should be the only one observed.

3.2 Data Description

"Golden balls" was first aired on June, 18th 2007 as a late afternoon (5pm) game show and is still running today.[10] In total, we have records of 222 episodes, with 203 regular and 19 special episodes. In the special episodes there are either (i) players that have been on the show before and have "lost" or (ii) only players of the same sex. The regular episodes always consist of two women and two men and all players are on the show for the first time. Importantly, the first series (40 episodes) was filmed prior to the show's television premiere. Hence, all players in these episodes had no chance to observe others playing the show.

For all episodes, we recorded variables describing the players (occupation, hometown, gender, race, and age) and the game (all true and stated ball values in rounds 1 and 2, the order of making statements in both rounds, votes the players received and submitted, the potential jackpot size, values of binned balls by each player, the player's intended strategy[11], the jackpot size, interactions of players before and in the final (handshakes, promises), and the final decision). Table 2 provides an overview of the data.

4 Strategic Considerations of the Players

Following the structure of the game show, we analyze the player's incentives to behave in a particular way. The final goal of each player has to be reaching the final round with a jackpot as high as possible and, most importantly, facing a player who intends to split, independently of whether the player herself prefers to steal or split. Thus, the players have to trade off these goals against each other.

In the pre-play, players base each of their two voting decisions on exogenous as well as endogenous criteria. We define exogenous criteria as characteristics of the players that are determined previously to the show, e.g., the player's age, gender, race, or place of residence. In contrast, endogenous criteria evolve during the course of the game, and are, for instance, the ball values dealt to the players, the order of making statements in round 2, or whether a player lied or not. Besides, the latter two criteria can be strategically used by the players. Players may be able to signal trustworthiness, since they can decide whether to lie or not about the content of their hidden back row balls. Making the statement first in round 2 may influence

[10] The show reaches up to 2.2 million people per episode which corresponds to a market share of 21% ("ITV strikes teatime gold", guardian.co.uk, July 3rd, 2007).

[11] Before the show starts, the players are individually and privately asked to explain which strategy they intend to play in the final. The recorded statement is only broadcasted to the television audience, but not to the other players or the audience in the television studio.

Table 2: Summary statistics

Variable	Mean	SD	Min	Max	N
Occupation					
Social Job[1] (1 = social job)	0.14	0.34	0	1	887
Student (1 = student)	0.08	0.27	0	1	888
Pensioner (1 = retired)	0.03	0.17	0	1	888
Place of residence					
England (1 = England, 0 = SCO, WAL, NIR, IRL)	0.85	0.36	0	1	886
Large City[2] (1 = population ¿ 268,300)	0.30	0.46	0	1	886
London (1 = London)	0.13	0.34	0	1	888
Gender, race, and age					
Gender (1 = male)	0.50	0.50	0	1	888
Race (1 = white)	0.92	0.27	0	1	888
Age[3] (1 = above 40)	0.43	0.50	0	1	888
Average cash ball in the show	5619.55	10374.12	10	75000	3108
Strategy statement[4] (0 = steal, 1 = split, 2 = other)	1.08	0.86	0	2	612
Round 1					
Value of open balls (balls 1 and 2)[5]	8802.64	13858.91	0	104000	888
Value claimed for balls 3 and 4	14265.86	13908.53	0	83000	888
Value of closed balls (balls 3 and 4)	7852.88	12315.07	0	83000	888
Number of killers in open balls	0.47	0.58	0	2	888
Number of killers claimed	0.23	0.43	0	2	888
Number of killers in closed balls	0.53	0.60	0	2	888
Player lied at least about one ball	0.53	0.50	0	1	888
Player lied at least about one value	0.32	0.47	0	1	888
Player lied at least about one killer	0.28	0.45	0	1	888
Number of killers taken to round 2	2.59	0.76	1	4	888
Round 2					
Value of open balls (balls 5 and 6)	9651.32	14275.73	0	103000	666
Value claimed for balls 7, 8 and 9	18421.19	16683.73	105	95000	666
Value of closed balls (balls 7, 8 and 9)	13352.47	16291.90	0	95000	666
Number of killers in open balls	0.44	0.58	0	2	666
Number of killers claimed	0.44	0.52	0	2	666
Number of killers in closed balls	0.75	0.69	0	3	666
Player lied at least about one ball	0.45	0.50	0	1	666
Player lied at least about one value	0.23	0.42	0	1	666
Player lied at least about one killer	0.28	0.45	0	1	666
Number of killers taken to final round	2.14	0.91	0	5	666
Value of balls taken to final round	23003.79	21134.80	150	143300	666
Final round (1st phase)					
Potential jackpot	51238.36	31261.51	5000	168100	444
Average cash ball	6932.27	12030.86	10	75000	1122
Number of killers	3.21	0.94	1	6	144
Number of killers to bin	1.74	0.92	0	4	144
Number of killers to win	1.47	0.88	0	4	144
Jackpot/Pot. jackpot	0.25	0.28	0.0001	1	444
Final round (2nd phase)					
Jackpot	13343.03	19247.56	3	100150	444
Decision (1 = split)	0.55	0.50	0	1	444
Outcome (0 = steal/steal, 1 = steal/split, 2 = split/split)	1.09	.75	0	2	222
Money taken home	4916.96	12000.86	0	100150	444
Money taken home (steal / split)	15693.11	20087.90	3	100150	94
Money taken home (split / split)	4783.64	8440.02	1.83	43950	148
Money left on the table	14426.34	20255.76	100	92330	108
Discussion (1 = starts discussion)	0.5	0.5	0	1	444
Handshake (1 = shake hands)	0.39	0.49	0	1	444
Mutual promise (1 = say promise)	0.25	0.43	0	1	444

[1] Note that we defined a social job as a job in which people care for other people, e.g., doctors, nurses, child minders, social workers, teachers, police officers, firemen, soldiers.
[2] Large cities are cities with more than 268,300 inhabitants (based on the Mid-2008 Population Estimates published by the Office for National Statistics).
[3] We estimated by personal judgment whether a player is below or above 40.
[4] Players secretly make this statement about the strategy they plan to play in the final before the show starts. It was introduced in episode 19, series 1.
[5] Killer balls are counted as zero for all value variables.

the other players' statements, e.g., if one player confesses a killer, the others may do the same. Further, during the discussions in round 1 and 2, they can, for instance, state why they distrust a certain player and try to convince the other players to vote this player off.
Once players reach the final round, they have to make sure that their opponent chooses the split ball in the final decision. Players use the discussion in the final round to reassure the opponent that they will cooperate, e.g., players promise each other to share the jackpot and/or shake hands on sharing it.

To summarize, the final decision as well as the voting decisions are functions of exogenous personal and endogenous characteristics of the players. Unfortunately, a game-theoretic analysis of the game is not feasible because the game is too complex and strategies are ill-defined. However, we will use the logic of backward induction to analyze the decisions made in the game. Therefore we start with analyzing the decision in the final round and then successively analyze the voting decisions made in round 2 and 1.

5 Analysis of Cooperative Behavior in the Prisoner's Dilemma

In this section we identify the influencing factors of cooperative behavior. We observe an average cooperation rate of 54.5%, which is higher than the one found in weak prisoner's dilemma experiments without communication, pre-play, and high stakes (e.g., Ortmann and Tichy (1999)). The rate is also slightly higher than the one observed in "Friend or Foe", another television game show experiment, (e.g., List (2006)). Further, we observe mutual cooperation in 33.3% and successful defection in 42.3% of the cases. Unilateral defectors take home three times as much money as mutual cooperators, £15,693 versus £4,784, and the average amount of money left on the table due to mutual defection is £14,426. Altogether 108 players left £1,558,045 on the table.

We will start the analysis in Section 5.1 with a discussion of the data and the variables that may have an influence on cooperative behavior. In Section 5.2 we will test the derived hypotheses in an empirical analysis. In addition we briefly present an alternative approach in Appendix A.2.

5.1 Possible Determinants of Cooperative Behavior

As we already pointed out in Section 2, the prisoner's dilemma under consideration is different in various aspects from the ones usually analyzed in the literature. In this section we will discuss the potential impact of those differences on the observed degree of cooperation, and present first results. The section is divided into four parts, (i) player characteristics, (ii) stake size, (iii) communication, and (iv) pre-play, following the presentation of variables in the regression tables in Section 5.2

(i) Player Characteristics

In this category we discuss variables that are exogenously determined. These are demographic player characteristics, which are also used to describe opponent- and team-characteristics, and a variable expressing the player's experience with the show.

Experience We define the players of the first 40 episodes (series 1) as unexperienced players. They had no chance to observe other contestants playing the game. In contrast, all later episodes have been filmed after the television premiere of "Golden Balls". Thus one could conjecture that the experienced players are more familiar with the show and therefore better in assessing whether cooperation or defection could be successful or not. But from the raw data, we do not observe a substantial difference, neither in the cooperation rate nor in the distribution of outcomes.[12]

Demographics Player's demographics are defined as exogenous characteristics of a player such as gender, age, race, place of residence, or occupation (descriptive results are reported in Table 8 and Table 9 in Appendix A.3). The relation between demographic characteristics and social behavior seems to be rather ambiguous. Deriving clear-cut hypotheses about the influence of these characteristics on the player's propensity to cooperate is therefore not possible.
Overall, there seems to be no difference between the cooperation rates of men and women. Concerning the rate of successful cooperation we find that it is lowest for female teams (28.6%) and highest for mixed gender teams (35.3%). The null hypothesis of no difference between the overall cooperation rate of men and women cannot be rejected (p=0.435) as well as the one for the mutual cooperation rate (p=0.503). Players above the age of 40 cooperate significantly more than players below 40 (p=0.001).[13] There are only small differences in the success rates of co-

[12] A two-sided binomial probability test can neither reject the null hypothesis of no difference between the cooperation rate of experienced (52.5%) and unexperienced (54,9%) players (p=0.372), nor the null hypothesis of no difference between the probability of mutual cooperation of experienced (34,1%) and unexperienced (30,0%) players (p=0.481), see Table 8 and Table 9 in Appendix A.3. This result is in contrast to the finding of Oberholzer-Gee, Waldfogel, and White (2010) who find an effect of learning for players in later episodes of "Friend or Foe". All tests used in this paper are two-sided binomial probability tests, unless stated otherwise.

[13] However, gender conditional on age tends to have an effect on the cooperation rate, i.e., women below 40 cooperate more than men below 40 and vice versa for men and women over 40. Note the

operation, teams of players below 40 have the lowest success rate. Whites are more likely to cooperate compared to non-whites, but the difference is not significant (p=0.334).
Based on a player's hometown, we construct variables indicating whether her place of residence is England, London, a small or a big city (see Table 2). Players living in England cooperate significantly less than players from other parts of Great Britain (p=0.000). In addition, if neither player lives in England the success rate of cooperation is 50.0% versus 32.5% if both players live in England, and 33.3% if it is a mixed team. The failure rate is highest for mixed teams and significantly higher than the one of English teams (p=0.002).[14]
Further, decisions made in the game might have implications beyond their immediate consequences, because the game is played in front of a large television audience and is therefore possibly being watched by friends, family members and/or colleagues. Depending on the player's occupation, it can be in her interest to appear trustworthy. For instance, police officers act as role models for observing the law and behaving correctly, or teachers are responsible for a moral education of children. These players have an incentive to behave in a fair way, especially when it comes to choosing the strategy in the prisoner's dilemma. We identify roughly 15% of contestants with an occupation for which their reputation is a valuable asset, and construct a variable "social job", including e.g., priests, policemen, firemen, childminders, and teachers. Having a social job might influence cooperative behavior because of two different reasons. On the one hand, players with a social job could be more cooperative because they want to show that they behave socially responsible. On the other hand, the causality could be vice versa: Having a social job could be a sign for being a cooperator itself, because a cooperative person chooses a job in which she can behave according to her preferences. In that case cooperative behavior would not be driven by the opportunity to appear trustworthy. Summarizing, it remains unclear whether we will observe an effect of having a social job.

Social Closeness The sociological literature argues that the degree of similarity between players has an impact on their social interactions. While some people might be willing to cooperate without discrimination, others are highly suspicious of people who are not like them and prefer to keep them at arm's length. In many social networks, e.g., friendships or business relations, one observes that individuals associate disproportionately with others who are similar to themselves, i.e., people are more likely to form social ties with others who are alike. This tendency of people

results concerning age should not be attached too much weight since the age categories are merely assessed by personal judgment.

[14]The hypothesis of no difference between the success rates of not-English and English teams (p=0.284), of not-English and mixed teams (p=0.454), as well as of English and mixed teams (p=0.849) cannot be rejected. Neither can the hypothesis of no difference between the failure rates of not-English and English teams (p=0.495) and of not-English and mixed teams (p=0.162) be rejected.

to relate to similar types is referred to as "homophily", first defined by Lazarfeld and Merton (1954).[15] Such motivated, we construct an index for the closeness between players by accounting for players' age, gender, race, occupational status, and place of residence (England). The index ranges from 0 to 1, weighting each component by one-fifth. For instance, if both players in the final are male, white, have a social job and live in England, the index takes a value of 0.8. Concerning the distribution, we observe the majority of players to have an index-value of either 0.6 (44%) or 0.8 (32%).

(ii) Stake Size

Categorizing the jackpot in five divisions (see Table 8 and Table 9 in Appendix A.3) we find that the cooperation rate decreases with a step-wise increase in the jackpot size. But, surprisingly, the rate declines sharply from 73.6% for jackpots below £500 to roughly 50% for jackpots above £500. The difference, taking the cutoff £500, is highly significant (p=0.000). Concerning the mutual cooperation rate, it is significantly higher if the two players face a jackpot below the level of £500 (p=0.000). This result is even more remarkable if one bears in mind that a stake size around £500 is already much higher than the one used in most laboratory experiments. At the same time, however, the cooperation rate rises with an increase in the potential jackpot, i.e., the highest possible jackpot the players could obtain after the first phase of the final round. Hence, the effects of the actual and the potential jackpot operate in opposite directions. One might presume that the players' perception of the actual jackpot depends on the potential jackpot, i.e., two actual jackpots equal in size will be judged differently depending on their difference to the potential jackpot. In Table 3 we explore this issue further.

We depict the cooperation rate for the five different jackpot categories and within each we split up the rate by the four categories of the potential jackpot, i.e., the difference between the highest potential and the actual jackpot is increasing within each category. Fixing the jackpot categories, we find that the cooperation rate almost always increases with the size of the potential jackpot. This corroborates the idea of a biased jackpot perception, that we will discuss in the following.

Expectation Players might build an expectation about the size of the actual jackpot depending on the observed size of the potential jackpot. This expectation is used to judge the size of the actual jackpot. But, computing the correct expectation is a rather difficult task if no computer is at hand. Therefore, players need some alternative method to calculate their expectation. As mentioned before, the first 40 episodes have been broadcasted before all other episodes were filmed. Henceforth,

[15]For a survey with respect to sociology see Jackson (2008) and with respect to cooperative game theory see van den Nouweland and Slikker (2001). Homophily is usually based on a variety of characteristics, including gender, race, age, region and education.

Table 3: Relation between jackpot and potential jackpot

Jackpot in £	**Potential Jackpot** in £	**Split** Row %	N
[3, 500]	[5000, 30000]	62.5	32
N=72	(30000, 45000]	85.7	14
	(45000, 75000]	75.0	12
	(75000, 168100]	85.7	14
(500, 2500]	[5000, 30000]	41.2	34
N=100	(30000, 45000]	59.5	42
	(45000, 75000]	44.4	18
	(75000, 168100]	100.0	6
(2500, 10000]	[5000, 30000]	50.0	30
N=102	(30000, 45000]	43.3	30
	(45000, 75000]	66.7	18
	(75000, 168100]	58.3	24
(10000, 30000]	[10000, 30000]	38.9	18
N=116	(30000, 45000]	45.7	46
	(45000, 75000]	52.9	34
	(75000, 168100]	55.6	18
(30000, 100150]	[30000, 45000]	50.0	6
N=54	(45000, 75000]	50.0	22
	(75000, 168100]	46.2	26

Note, that the difference between the jackpot and the potential jackpot is increasing with an increasing potential jackpot per jackpot category.

we assume players to take the observed average ratio between the jackpot and the potential jackpot in series 1 as an estimate to roughly calculate their expectation. The average jackpot in series 1 is £13,066 which corresponds to 27.5% of the average potential jackpot of £47,526. This ratio is multiplied by the observed potential jackpot in each episode, and determines the players' expected jackpot.[16] Depending on whether the jackpot is above or below the player's expectation, the propensity to cooperate changes. The cooperation rate is significantly higher (p=0.002) if the jackpot is below the expectation, and cooperation is much less successful if the expectation threshold is taken, i.e., 18.4% versus 41.1% of mutual cooperation.

(iii) Communication

Apart from communication that takes place in round 1 and 2, and in the first phase of the final round, players explicitly get some time to discuss the strategy they

[16] The ratio between the jackpot and the potential jackpot observed in the episodes following series 1 is 25.7% which is very similar to the ratio observed in the episodes of series 1.

intend to play in the prisoner's dilemma. The players use this time to assure each other their willingness to cooperate, i.e., to choose the split ball. As described in Section 2, studies have shown that especially face-to-face communication, involving a mutual agreement to cooperate, increases the cooperation rate significantly. We observe that 24.8% of the players voluntarily promise each other to cooperate. In addition to verbal communication, 39.2% of the players shake hands to corroborate their intention to split, and 41.4% out of those do both, i.e., they shake hands and promise each other to share the jackpot. We define dummy variables to control for mutual promises, handshakes and for whether the contestant starts the final discussion. We expect handshakes and promises to increase successful cooperation.

(iv) Pre-Play

The next three potential determinants of cooperative behavior evolve within the pre-play.

Lying Lying is rather common during the pre-play rounds of the game show and might be thought of as an inherent part of the game. Players are concerned about maximizing the stake size, thus having low values or killer balls increases the probability of being voted off. Driven by the fear of being eliminated from the game when having "bad" balls, the contestants bluff their way to the final. But a player is revealed as a liar after each round, and might get a reputation of being not trustworthy, which possibly prevents her from lying. Analyzing our raw data, we find that 43% of the players who reach the final lied about the content of their balls in round 1 and 37% in round 2. A possible implication of lying could be that liars may want to repay their "guilt" and therefore are more tempted to cooperate. But a player who has not lied might perceive a liar as untrustworthy per se and thus is less willing to cooperate. We control for the potential effects of lying by introducing dummy variables for whether the player or her opponent has lied about a cash value or a killer during the two rounds of pre-play, since we believe that the perception of concealing a killer may differ from that about overstating a cash amount.

Kindness In addition, we include variables linked to kindness, experienced kindness, and its repayment in our analysis. Firstly, we account for the impact of the voting decision on the behavior of those contestants who remain in the show. After each round of the pre-play, contestants need to secretly cast a vote against a certain player whom they want to leave the game. It can happen that a player in the final has voted against her opponent during the pre-play. This might influence the player's behavior in the final: A player is less likely to cooperate, since she expressed her dislike against the other player before. In this respect we construct a dummy variable that identifies a player who voted against her opponent.
Secondly, we define a variable termed "should have left the game" in order to investigate whether a player responds to experienced kindness. The variable is constructed

as follows: First we rank the three players in round 2 with respect to their weighted sum of cash values and killer balls. The dummy points at the player with the lowest weighted sum. From a purely monetary perspective, this player should be voted off the game. But if such a player nevertheless reaches the final round, she is aware of owing her "survival" to her opponent.[17] In this respect one could surmise that she is more likely to split the jackpot in order to pay back her survival.

Luck At last, we want to focus on the first phase of the final round, in which the jackpot is built by an alternating selection of balls. The player who starts to select the first balls to bin and win is the player who brought along the higher sum of cash values, i.e., contributed most to the potential jackpot. The mean difference between the player's contributions is £1,678 without accounting for the possible damage caused by killer balls. The value of the resulting jackpot is determined purely at random, but one player might be more lucky than the other, i.e., chooses higher values or bins more killer balls. We control for those effects, constructing three dummy variables: One for the player who contributes most to the potential jackpot, one for the player who selects the highest values, and one for the player who bins most killer balls. These players could feel entitled to a larger piece of the pie and are therefore less likely to cooperate. This would be in line with the findings on entitlement and fairness of Rutström and Williams (2000).

5.2 Regression Analysis

In order to explore the individual decision process when playing the prisoner's dilemma game, we estimate bivariate probits of the probability that player i chooses split or steal as a function of own and opponents' characteristics as well as variables determined in the pre-play (see Table 4).[18] Additionally, to analyze team cooperation rates, we estimate ordered probits (see Table 5 and Table 10 in Appendix A.3).

[17] In order to rank the players we use the *ex-post* cash-killer-criterion which is described and discussed in detail in Section 6. We assume that a player, who does have the lowest weighted monetary amount is aware of this and does value her survival. Often the players address their pass to the final round during the final discussion and thank their opponent for having taken her so far.

[18] In addition, we estimate the same probits including one additional dummy variable, namely whether player i "voted against (her) opponent" in the pre-play which results in a significantly negative effect on cooperation. We exclude the dummy in our main analysis, since including it reduces the data set by 55 observations which is due to a voting result of 2:1:1:0 in round 1 or 1:1:1 in round 2 (in these cases it is analytically not possible to trace back the players' individual voting decision). Except for the episodes with a tie, the outcome of the voting decision is 2:1:0 in round 2, such that none of the final players received a vote from their opponent. Thus, the control variable only comprises of the voting result in round 1. Additionally, we can only control for the voting decision made by the particular player herself, and not whether this player received a vote by her opponent in the final, since after round 1 the players can only speculate who had cast a vote against them. Therefore we can only identify 18 out of 390 players to have casted a vote against her final opponent. Thus, the variable "voted against (her) opponent" has not much explanatory power.

We order the outcomes by coding the team outcome as equaling 0 if both players choose steal, equaling 1 if one player chooses steal and the other chooses split, and equaling 2 if both players choose split.

Results for Unilateral Cooperation

We estimate bivariate probits on the probability that player i chooses split ($y = 1$), or steal ($y = 0$) as a non-linear function of exogenous demographic player characteristics, D, and variables that evolved during the game, G, including a constant and one interaction term, namely the interaction of "handshakes", x_1, and "promise", x_2. The conditional probability that player i chooses split is

$$P(y = 1|x_1, x_2, D, G) = \Phi(\alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 + D\theta + G\nu) = \Phi(m),$$

where $\alpha, \beta, \theta, \nu$ are parameters to be estimated, $\Phi(\cdot)$ is the standard normal cumulative distribution function, and m denotes the index $\alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 + D\theta + G\nu$.
The marginal effect for the k-th independent variable is computed as

$$\frac{\partial P(y = 1|x_1, x_2, D, G)}{\partial x_k} = \phi(m)\beta_k \quad k = 2, ..., K$$

where $\phi(\cdot)$ is the standard normal density function. The magnitude of the derivative is proportional to $\phi(m)\beta_k$. A change in one of the independent variables results in an effective percentage change in player i's likelihood to cooperate.[19]

Table 4 reports the estimation results of four probit models, which differ with respect to the included variables in the group of stake size and pre-play. Model (1) and (3) include the continuous variables jackpot and potential jackpot, while models (2) and (4) include the dummy variable describing whether the expectation of the resulting jackpot is met or not. In addition to the controls for personal players' demographics, stake size, and communication, in models (3) and (4) variables determined in the pre-play are introduced.

Throughout, addressing demographics, we find that age, whether a player lives in England, or whether both players live in a small city have a significant effect on

[19] If x_k is a dummy variable, the marginal effect is computed as the discrete difference

$$\frac{\triangle P(y = 1|x_1, x_2, D, G)}{\triangle x_k} = \Phi(m|x_k = 1) - \Phi(m|x_k = 0), \quad k = 2, ..., K.$$

Note that the marginal effect of the interacted dummy variable "handshakes" (x_1) and "promise" (x_2) is equal to the discrete double difference

$$\frac{\triangle^2 P(y = 1|x_1, x_2, D, G)}{\triangle x_1 \triangle x_2} = \Phi(m) - \Phi(\beta_1 + \alpha + D\theta + G\nu) - \Phi(\beta_2 + \alpha + D\theta + G\nu) + \Phi(\alpha + D\theta + G\nu).$$

Table 4: Results from binary probit on unilateral cooperation (1)

$y = 1$ (Split)	Marginal Effects							
	Model (1)		**Model (2)**		**Model (3)**		**Model (4)**	
Player Characteristics								
Unexperienced	-0.028	(0.069)	-0.050	(0.069)	-0.019	(0.074)	-0.041	(0.073)
Male	-0.018	(0.059)	-0.017	(0.058)	-0.019	(0.060)	-0.018	(0.060)
Age (>40)	0.164***	(0.064)	0.161**	(0.063)	0.174***	(0.066)	0.172***	(0.065)
White	0.117	(0.148)	0.113	(0.145)	0.052	(0.147)	0.046	(0.143)
England	-0.269***	(0.078)	-0.267***	(0.077)	-0.274***	(0.082)	-0.271***	(0.081)
London	0.001	(0.103)	0.003	(0.100)	-0.059	(0.107)	-0.066	(0.104)
Large City	-0.054	(0.077)	-0.051	(0.075)	-0.024	(0.081)	-0.018	(0.080)
Student	-0.009	(0.096)	0.001	(0.095)	-0.020	(0.095)	-0.014	(0.095)
Pensioner	-0.143	(0.160)	-0.160	(0.163)	-0.126	(0.164)	-0.145	(0.167)
Social Job (Reputation)	-0.017	(0.087)	-0.032	(0.087)	-0.016	(0.090)	-0.033	(0.090)
Team Characteristics								
Index (Social Closeness)	0.458	(0.309)	0.469	(0.306)	0.592*	(0.322)	0.606*	(0.318)
Team Male	-0.147	(0.099)	-0.152	(0.097)	-0.183*	(0.100)	-0.184*	(0.097)
Team Female	-0.054	(0.095)	-0.058	(0.095)	-0.083	(0.097)	-0.084	(0.097)
Team Age> 40	-0.011	(0.103)	-0.009	(0.103)	-0.007	(0.106)	-0.001	(0.107)
Team Age< 40	-0.049	(0.091)	-0.055	(0.090)	-0.073	(0.095)	-0.075	(0.093)
Team White	-0.118	(0.122)	-0.124	(0.118)	-0.108	(0.124)	-0.116	(0.121)
Team England	-0.019	(0.093)	-0.001	(0.093)	-0.021	(0.097)	-0.002	(0.096)
Team Large City	-0.127	(0.101)	-0.128	(0.100)	-0.147	(0.101)	-0.145	(0.101)
Team Small City	-0.141**	(0.067)	-0.127*	(0.067)	-0.143**	(0.069)	-0.126*	(0.068)
Opponent Characteristics								
Opp. Student	0.087	(0.097)	0.095	(0.095)	0.107	(0.098)	0.111	(0.097)
Opp. Pensioner	0.067	(0.162)	0.049	(0.159)	0.053	(0.171)	0.032	(0.168)
Opp. Social Job	0.040	(0.085)	0.027	(0.085)	0.087	(0.086)	0.073	(0.086)
Stake Size								
log(Jackpot)	-0.057***	(0.014)			-0.057***	(0.015)		
log(Pot. Jackpot)	0.097**	(0.048)			0.077	(0.050)		
Jackpot < Expectation			0.162***	(0.056)			0.173***	(0.059)
Communication								
Started Discussion	-0.008	(0.048)	-0.009	(0.047)	-0.005	(0.049)	-0.006	(0.049)
Handshakes	-0.151**	(0.067)	-0.179***	(0.066)	-0.167**	(0.068)	-0.196***	(0.067)
Promise	-0.032	(0.108)	-0.063	(0.107)	-0.060	(0.109)	-0.095	(0.108)
Handshakes*Promise	0.281**	(0.139)	0.309**	(0.170)	0.339**	(0.142)	0.372***	(0.054)
Pre-play								
Acc. Most Money					-0.098*	(0.058)	-0.099*	(0.057)
Selected Higher Values in Bin/Win					-0.148*	(0.079)	-0.157**	(0.077)
Binned Most Killers in Bin/Win					-0.091	(0.090)	-0.092	(0.088)
Lied About Cash Value					-0.105*	(0.059)	-0.106*	(0.059)
Lied About Killer					-0.018	(0.055)	-0.017	(0.055)
Opp. Lied About Cash Value					0.019	(0.058)	0.014	(0.058)
Opp. Lied About Killer					-0.048	(0.056)	-0.041	(0.055)
"Should Have Left The Game"					0.133**	(0.062)	0.144**	(0.061)
Wald $\mathcal{X}^2$	61.23***		55.18***		74.06***		69.14***	
Log-Likelihood	-273.26		-277.81		-264.75		-268.63	
Pseudo R^2	0.10		0.09		0.13		0.11	
N	441		441		440		440	
Number of Clusters	222		222		222		222	

standard errors in parentheses are corrected for episode clusters; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

the likelihood to cooperate. If player i is above the age of 40, she is about 16% more likely to cooperate, i.e., split. But, a player who lives in England, compared to any other part of Great Britain, is roughly 27% more likely to be a defector, i.e., steal. Additionally, if both final players live in a small city, then player i's likelihood to cooperate decreases by up to 14%. All three effects are very robust with approximately the same magnitude across the four models. The results on players' gender, race, and occupational status, however, exhibit no significant effects. We also find no effect for player i's experience, i.e., the control for the first series has no significant effect, indicating that players are not able to profit from a learning effect if they could watch the game show on television before.

The results on stake size support our findings gained in Section 5.1: As suggested, the higher the actual jackpot, the less likely player i cooperates; while, the higher the potential jackpot, the more likely player i cooperates. In addition models (2) and (4) highlight our descriptive finding that a player is more willing to cooperate if the actual jackpot is below her expectation, i.e., her likelihood to cooperate significantly increases by roughly 16%. All effects are independent of player's characteristics or communication, and are highly robust.

Addressing the controls for communication, we find that neither starting the final discussion nor voluntarily promising each other to cooperate are significant determinants. But, we find a negative effect of shaking hands: If both final contestants shake hands during the final discussion, each player actually is more likely to defect. Thus, handshakes seem to serve as an instrument to manipulate the opponent's attitude towards cooperation. Whether shaking hands is perceived differently depending on a promise made at the same time, we interact both dummy variables. As the results show, we find a positive significant interaction effect: Shaking hands in combination with a promise actually increases the player's likelihood to cooperate. We will further explore whether these effects help cooperators to coordinate by looking at team outcomes in the next subsection.

In models (3) and (4) we introduce controls describing pre-play determinants. We find that a lie about a cash value is treated differently with respect to its influence on cooperation. If player i lied about a cash value, she is roughly 10% more likely to defect in the prisoner's dilemma, but concealing a killer has no effect, neither does a lie of her opponent. Regarding the control indicating that player i should have left the game before, player i is roughly 14% more likely to cooperate. As hypothesized a player who should have been voted off the game, but nevertheless made it to the final, is likely to pay back the opponents' confidence. Further, we find that both, having accumulated more money as well as having selected the higher values when building the jackpot, have a significantly negative impact on the players' likelihood

to cooperate. As suggested, a player might feel entitled to a larger piece of the pie, since she contributed more to the stake size. Testing for any interaction effect with respect to a player's expectation, we find that a player who accumulated more money to the jackpot and whose expectation is not met, is significantly more likely to steal. This result suggests that a player's perception of the jackpot is correlated with her contribution to the potential jackpot.
Besides, the introduction of the pre-play controls results in two additional effects regarding team characteristics. We find that a male player is significantly less likely to cooperate with a male opponent, indicating that men are more competitive when facing the same sex. Another significant determinant of cooperative behavior is the index of social closeness between players. The more similar both final players are with respect to their age, gender, race, and place of residence, the more likely player i is to cooperate with her opponent. This finding suggests, that in-group biases may be present.

Results for Mutual Cooperation

To understand why players arrive at different outcomes in the prisoner's dilemma, we estimate ordered probit models. We observe the discrete variable y that can take on three values, i.e., it equals 0 if both players choose steal, it equals 1 if one player chooses steal and the other chooses split, and it equals 2 if both players choose split. The boundaries between the three cases are determined by the threshold (ξ_i), which needs to be estimated along with the rest of the parameters. The probabilities of the three events $y = 0; 1; 2$ are given by $P(y = 0) = \Phi(\xi_1 - m)$, $P(y = 1) = \Phi(\xi_2 - m) - \Phi(\xi_1 - m)$, $P(y = 2) = \Phi(m - \xi_2)$, where $m = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 + D\theta + G\nu$. The marginal effect of d_k (g_k) for the $j-$th response is computed as[20]

$$\frac{\partial P(y = j|x_1, x_2, D, G)}{\partial x_k} = [\phi(\xi_{j-1} - m) - \phi(\xi_j - m)]\beta_k.$$

[20]If d_k (g_k) is a dummy variable, then the marginal effect is computed as the discrete difference

$$\triangle P(y = j|x_1, x_2, D, G) = P(y = j|(x_1, x_2, D, G) + \triangle x_k) - P(y = j|(x_1, x_2, D, G)).$$

Note that the marginal effects of the variables that are interacted involve the coefficient of the interaction term. Therefore, the marginal effect of x_1 (analog for x_2) for the j-th response is calculated as

$$\frac{\partial P(y = j|x_1, x_2, D, G)}{\partial x_1} = [\phi(\xi_{j-1} - m) - \phi(\xi_j - m)](\beta_1 + \beta_{12} x_2);$$

and the magnitude of the interaction effect for the j-th response is given by

$$\frac{\partial P(y = j|x_1, x_2, D, G)}{\partial x_1 \partial x_2} = [\phi(\xi_{j-1} - m) - \phi(\xi_j - m)]\beta_{12} - [\phi'(\xi_{j-1} - m) - \phi'(\xi_j - m)](\beta_1 + \beta_{12} x_2)(\beta_2 + \beta_{12} x_1),$$

where $\phi'(\cdot)$ denotes the first derivative of the normal density function w.r.t. its argument. Standard errors are computed by the delta method.

Table 5: Results from ordered probit on outcomes in the PD (1)

$y = 0; 1; 2$	Marginal Effects					
	Steal/Steal (0)		**Split/Steal (1)**		**Split/Split (2)**	
Team Characteristics						
Team Unexperienced	0.000	(0.063)	0.000	(0.013)	0.000	(0.077)
Team Male	0.091	(0.089)	0.006	(0.011)	-0.097	(0.083)
Team Female	0.010	(0.064)	0.002	(0.012)	-0.012	(0.075)
Team > 40	-0.068	(0.065)	-0.023	(0.032)	0.091	(0.096)
Team < 40	0.103	(0.066)	0.012	(0.011)	-0.115	(0.070)
Team England	0.121**	(0.050)	0.041	(0.026)	-0.162**	(0.071)
Team Small City	0.079	(0.048)	0.016	(0.013)	-0.095	(0.058)
Index (Social Closeness)	-0.302*	(0.162)	-0.063	(0.635)	0.364*	(0.195)
Pre-Play						
Team Never Lied	-0.046	(0.059)	-0.013	(0.022)	0.059	(0.081)
Team Lying	0.028	(0.053)	0.005	(0.010)	-0.033	(0.063)
Communication						
Handshakes	0.078	(0.054)	0.016*	(0.009)	-0.094	(0.058)
Promise	-0.081	(0.053)	0.127***	(0.016)	0.098	(0.064)
Handshakes*Promise	-0.295**	(0.129)	0.029	(0.046)	0.324**	(0.137)
Stake Size						
log(Jackpot)	0.051***	(0.013)	0.011	(0.107)	-0.062***	(0.015)
log(Pot. Jackpot)	-0.081*	(0.043)	-0.017	(0.178)	0.098*	(0.051)
Wald $\mathcal{X}^2$	36.90***					
Log-Likelihood	-219.55					
Pseudo R^2	0.08					
N	54		94		74	
Number of Clusters	222					

Standard errors in parentheses are corrected for episode clusters; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The results for the three different outcomes are presented in Table 5 and Table 10 in Appendix A.3.

Concerning team characteristics, Table 5 shows that teams of English players are more likely to defect. But the more similar both team players are with respect to their age, gender, race, and place of residence, i.e., the higher the index value, the more likely they manage to successfully cooperate. Addressing the division of team by gender, age or having lied in the pre-play, there are no considerable differences. The results also highlight the significance of handshakes and promises. Teams that shake hands or promise each other to cooperate, are more likely to miscoordinate. In addition, handshakes in combination with a promise increase the likelihood of mutual cooperation and decrease the one of mutual defection. As the analysis of the raw data suggests, we find a highly significant and inverse effect of the actual and potential jackpot. Both players are 5% more likely to defect when the stakes are large, and are 6% less likely to cooperate. In contrast, teams are almost 10% more likely to cooperate when the potential jackpot increases. The results in Table 10 in Appendix A.3 support the discussed findings, highlighting that the players' expectation about the stake size is also a significant influencing factor of mutual cooperation. If both players' expectation about the jackpot is above the actual one, they are 17% more likely to cooperate, but 16% more likely to defect.

Summary We identify various player characteristics (e.g., age, living in England, or social closeness), stakes size, and communication, as well as pre-play to be significant influencing factors of unilateral and mutual cooperation. Most noticeable we find a robust and substantial negative effect of the actual stake size on cooperation, i.e., the higher the jackpot the more likely players are to defect. Controlling for the effect of handshakes and voluntarily stated promises we find that players who shake hands are more likely to defect, while handshakes in combination with a promise are likely to result in cooperation and successful coordination. Both effects are robust and independent of player characteristics and pre-play determinants. We are not aware of any other study having shown similar effects.

6 Pre-Play Decision Making: Voting Behavior

As the results from the probit regressions suggest, the opponents' characteristics play a decisive role for cooperative behavior. Therefore, we now draw our attention to the pre-prisoner's dilemma play, i.e., the selection of the two finalists. Starting with four contestants, each player faces the decision for whom to vote to leave the game in round 1 and 2. The players' voting behavior will be a function of observable characteristics and subjective criteria that maybe inconsistent with one another: Firstly, players have powerful monetary incentives and would like to vote off the player who has the lowest cash values or most killers in her golden balls. But, at the same time, players need to evaluate the opponent's character in view of the final round, i.e., assess her trustworthiness, sympathy, or susceptibility to manipulation. Finally, the players need to vote in a way that increases their own survival, thus their optimal action depends critically on the belief about how other players vote.

In the next three sections we will show how the players balance their voting decision, bearing in mind the stake size, the opponent's character and their own survival. In Section 6.1, we discuss the expected voting behavior with the help of three objective evaluation criteria. In Section 6.2 we briefly describe the impact of personal player characteristics as well as round-specific determinants. Finally, in Section 6.3 we empirically test the validity of the objective criteria.

6.1 Objective Criteria

Each episode, before the players have to decide against whom to cast a vote, the show host reminds the players to "keep in the cash, and kick out the killers". Following this prompt, we describe the player's voting decision by means of three objective criteria assuming that it is a player's aim to maximize the potential stake size. Each episode and round these criteria predict one particular player who *should* be voted off: The **cash- (CC)** and **cash-killer-criterion (CKC)** are constructed on the basis of the (weighted) monetary values of balls and declare the player with the lowest amount of money to be voted to leave the game. While we count a killer ball as a ball with zero value in the CC, we attach the killer balls a weight of 0.1 in the CKC, i.e., one killer ball reduces the monetary value to one-tenth of the original value, a second killer ball reduces it to one-hundredth of the original value and so forth. The **killer-criterion (KC)** focuses on the number of killer balls per player, and accordingly declares the player with the highest number of killers to be voted off.

Further, within each criterion we distinguish three different time-dimensions, i.e., we determine the prediction of each criterion separately taking into account (i) the two opened balls on the front row (**ex-ante**), (ii) the two open balls and the statements of the hidden back row balls (**stated**), and (iii) all revealed balls (**ex-post**[21]).

By means of these three, respectively nine criteria, we analyze to what extent each criterion explains the player's voting decision within and between round 1 and 2. Descriptive results are reported in Tables 11 to 13 in Appendix A.3.[22]

First we want to look at the proportions of players who are effectively voted off in line with the three criteria (see Table 11 in Appendix A.3). Focusing on the time-division of each criterion, in round 1 we find that most players vote in line with the prediction of the *ex-ante* CKC and *ex-ante* CC, as well as of the *stated* KC. In round 2 instead, the *ex-post* CKC and the *ex-post* CC dominate, but the *stated* KC again yields the best prediction. Overall the KC, especially when looking at the *stated* values, fits best: In round 1, 81.1% of players who are voted off have the highest number of killer balls both on their front row as well as stated on their hidden back row balls; in round 2 this proportion slightly reduces to 70.3%, but still exceeds the CC and CKC.

The findings are confirmed when considering for each criterion the proportions of players who received a vote when predicted, additionally distinguished by gender (see Table 12 in Appendix A.3).

[21] The *ex-post* criteria serve to test whether the players use the *ex-ante* criteria as a best estimation of the true state.

[22] Note that we exclude those episodes which have a voting result of 2:1:1:0 in round 1 or a tie in round 2, since it is analytical impossible to reconstruct the players' individual decision. Additionally, in Table 12 and Table 13 we restrict the sample to only those players who take part in both rounds (with an almost equal share of males (48.5%) and females (51.5%)); thereby we can compare the voting results for both rounds taking the same player's decisions into account.

As above, we focus on the time-dimension of each criterion and find that the players most frequently vote in line with the *ex-ante* CKC and CC in round 1, but in line with the *ex-post* CKC and CC in round 2. Concerning the KC, players vote in line with the *stated* KC in round 1 and the *ex-ante* KC in round 2. Separating these findings by gender, we observe that significantly more males than females vote in line with the *stated* KC and *ex-ante* CKC in round 1 ($p = 0.024$ and $p = 0.034$) whereas in round 2 more females vote in line with the *ex-post* CC ($p = 0.021$).
Most noticeable, in both rounds the players take the statements about killer balls seriously, although one might argue that statements are only cheap talk and should therefore be ignored. But a statement about a killer ball has to be treated different from stating a particular value. In our setting, players have a strong incentive to lie about a killer ball, since it threatens them progressing in the game. If players nevertheless state to have one, this message is "self-signaling" and not cheap talk: If a player states to have a killer ball it is the truth.

A first result is that players seem to base their voting decision on objective criteria, but switch within the time-dimension of the criteria from round 1 to 2. This switch maybe explained by the different amount of information a player has at a certain time.

Information Based Separability of Players

In the two pre-play rounds the players have different information about the distribution of values. In round 1, the players face a situation in which they base their voting decision on an *ambiguous* distribution of outcomes, i.e., only the values of the revealed front row balls are common knowledge. In round 2 the players have additional information. After the voting decision in round 1, all contestants need to reveal their true values on the back row. The twelve balls carried over from round 1 to round 2 are now common knowledge to all remaining contestants, and only the two new added cash values are unknown. Hence, a player can be in two different states: First, if both new values are within the revealed balls on the front row, or a particular player has at least one new value on her hidden back row and the other is observable on any other player's front row, she knows the exact distribution of values in play. From an informational point of view a player who knows all ball values in play, makes her voting decision in a situation where only the precise allocation of each value is *uncertain*. Second, if both new values remain unobservable, a player again lacks information, but not as much as in round 1.[23] Thus, using

[23] We also analyzed the case when only one of the new ball values is known to a player, termed *partial ambiguity* (see Table 13 in Appendix A.3). But for the sake of clarity we limit the discussion to the cases when both new values are either known or not. Naturally the extent of information about a state's probability influences the players' willingness to bet on the state. Camerer and Weber (1992) review the empirical and theoretical literature on ambiguity in decision making.

the statements about the hidden ball values, the players are able to infer - up to a certain extent - whether a contestant lies.

We expect that a player, who faces *uncertainty* about the allocation of balls makes her voting decision in consideration of all "true" values, and weights the utility of the outcome by the probability of obtaining it. These players tend to vote by means of the *ex-post* criteria. This effect should be more pronounced compared to the one observe for players in a situation of *ambiguity*. Here, they should vote most frequently by means of the *ex-ante* criteria.

In what follows we refer to Table 13 in Appendix A.3 that presents proportions of the players' voting decision by means of the three criteria and its time-divisions as well as player's informational background. We restrict the data set to compare the same 573 players in round 1 and 2, of which we identify 50 players to be in an *uncertain* state, and 241 players to be in an *ambiguous* one in round 2. In round 1 all 573 players are in the same *ambiguous* situation.

As suggested, we find that the proportion of *uncertain* players who vote in line with the *ex-post* CKC is significantly higher (p=0.004 and p=0.000) than of *ambiguous* players. Additionally, the spread between proportions of players who consider the *ex-post* or the *stated* prediction within the CKC is much larger for players facing *uncertainty* than *ambiguity*.[24] This indicates that those players are able to infer which player overstates her hidden values on the back row, and in return cast a vote against her. The KC is again special, firstly, due to the self-signaling message when stating a killer ball, and secondly because the number of killer balls seem to be the strongest determinant for player's voting behavior.

Summary With the help of the time-dimension within the three criteria we find a possibility to explain the decision making of more than two thirds of the players. The players' decision may origin in an objective evaluation of their opponents, giving most weight to killer balls. Given the predictions of all criteria, we find contrary voting patterns due to informational differences between both rounds of pre-play, i.e., players switch from *ex-ante* criteria in round 1 to *ex-post* criteria in round 2.[25]

[24]For instance, in round 2 70% of all player facing *uncertainty* vote by means of the *stated* CKC, but only 55% of all players in round 1, compared to 64% of players facing *ambiguity* in round 2. The same holds for the *ex-post* CKC, as well as for males and females in both criteria. Besides we find a different voting pattern for males and females facing *uncertainty*: A much larger proportion of males votes in line with the *ex-ante* CC and CKC than females in round 2, while these are almost equal when players are *ambiguous*, or in round 1.

[25]Over the whole sample, we find only 22 contestants (2.8%) who do not vote in line with neither criterion, and only 65 contestants (8.3%) who never vote in line with an *ex-ante* criterion.

6.2 Subjective Criteria and Pre-Play Determinants

Regarding players' choice of their counterpart for the final round, besides the objective criteria, subjective personal valuations as well as observed behavior in the first two rounds are likely to play a decisive role.
First, it is likely that people have different "tastes" for others. We find that women are more likely to vote against men and vice versa. In round 1, males cast a vote against females in 65% and females against males in even 75%. The difference to vote against the opposite sex is highly significant ($p = 0.000$). In round 2 we find that only females are more likely to cast a vote against males (52%, $p = 0,096$), but that males are significantly more likely to vote against their same sex (54%, $p = 0,064$). This finding suggests that in-group biases may be prevalent, especially in round 1.[26] Apart from gender differences, we find that non-whites reach the final round significantly less frequently: 63% of non-whites do not reach the final ($p = 0.000$).
Second, we ask whether the order in which players announce the content of their hidden balls impacts on the players' voting decision. The determination of the order differs between rounds: In round 1, the show host calls on a particular player to start telling what is on her hidden back row balls. Usually this is the player with the weakest front row. Thus, in round 1 the order of statements is exogenously determined by the show host. In round 2 instead it is endogenous. The show host asks the players who wants to open up the round. On the one hand starting to report the content of the hidden back row balls helps to state high values, especially if it is the truth, and thereby turning the focus on the opponents' balls. On the other hand, the player who begins to state her hidden values cannot make her statement dependent on her opponents' statements, e.g., if all other players confess to have a killer ball a player who states her values afterward might be more likely to confess a killer as well. After round 2, we observe that only 26.1% of the players who announce first are effectively voted to leave the game, but the second or third player is voted off in 38.7% and 35.1%, respectively.[27] Therefore, we expect that the order in round 2 has explanatory content in the sense that a player has a lower propensity to receive a vote or is less likely voted off if she makes her statement first. In round 1 we do not expect the order to have additional explanatory power, since the player is either selected randomly or due to her weak front row. The effect of a weak front row on the likelihood of receiving a vote is already captured by the objective criteria.

[26] In addition, we find that males receive a vote more frequently than females. In round 1, 55% of males receive a vote ($p = 0.000$), in round 2 53% ($p = 0.012$).

[27] The test for the difference between the order of statements is highly significant between the first and second player ($p = 0.000$), and the first and third player ($p = 0.001$). There is no difference between being the second or third announcer ($p = 0.241$).

6.3 Regression Analysis

In this section we determine which of the objective as well as subjective determinants, explain the observed voting pattern best and thus affect a player's survival within the two rounds of pre-play. Addressing the objective criteria, which we discussed in Section 6.1, we construct variables for each criterion and their corresponding time-dimension. For each criterion the variables are composed of (i) the sum of the two open balls, (ii) the sum of the stated values on the back row, and (iii) a dummy indicating whether the player made a truthful statement about her hidden back row balls or not.

We expect that the values or number of killers in the open balls on a player's front row affect the decision about whom to cast a vote against in both rounds. But, the statements of the hidden back row balls are only considered in the voting decision in round 2, since in round 2 the players have some information about their possible content. More precisely, the higher the amount of cash in the two open balls, the more likely a player survives the pre-play, but the more killer balls a player has, the more likely she is eliminated from the game.

In addition, we control for whether it is a good strategy of players to tell the truth about the content of their hidden back row balls. Although in round 1 the players have no information about the distribution of balls in play, an honest player might be able to convince the others that her statement is true, because she is e.g., not nervous. Further, we control for the effect of lying by including a dummy "lied in round 1" in the regression for round 2, i.e., the dummy indicates whether a player lied in round 1. A player who lied in round 1 takes the risk of getting a reputation of being untrustworthy, which she may suffer from in round 2. We observe that a substantial amount of players lies in round 1 (53%) as well as in round 2 (45%). The average overstatement is £6,413 in round 1, and £5,069 in round 2.

Concerning the subjective criteria and pre-play determinants (Section 6.2), we control for the effects of players' age, gender, race, and place of residence as well as the effects of lying and the order of statements in the regression analysis. We expect that voting incentives switch between rounds such that players attach more weight to the objective criteria in round 1, and in round 2 shift weight to personal judgment about the opponent's sympathy or trustworthiness with regard to the final.

We estimate a probit on the likelihood that a player is voted off the game (see Table 6) as well as an ordered probit where we look at the determinants impacting on the likelihood a player receives 0,1,2, or 3 votes in round 1 (see Table 14 in Appendix A.3), and 0,1, or 2 votes in round 2 (see Table 15 in Appendix A.3). In all regressions we simultaneously control for the CC and KC (model (1)), and separately for the CKC (model (2)), which is a mix between the other two. Again, we present marginal effects instead of coefficient estimates.

Table 6: Binary probits on voting behavior in round 1 and 2

$y_i = 1$ (player i has to leave the show)

Round 1	Marginal Effects			
	Model (1)		**Model (2)**	
Player Characteristics				
Male	0.040	(0.035)	0.040	(0.035)
Age > 40	-0.002	(0.035)	-0.004	(0.034)
White	-0.117*	(0.067)	-0.109*	(0.066)
England	0.023	(0.044)	0.023	(0.043)
Order of Statements	0.024	(0.042)	0.028	(0.041)
Cash-Criterion (CC)				
log(Value Open Balls)	-0.068***	(0.010)		
log(Value Stated Balls)	-0.006	(0.014)		
Truthful Statements	-0.051	(0.037)		
Killer-Criterion (KC)				
No. Killers Open Balls	0.142***	(0.036)		
No. Killers Stated Balls	0.040	(0.046)		
Truthful Statements	-0.091**	(0.042)		
Cash-Killer-Criterion (CKC)				
log(Whgt. Value Open Balls)			-0.074***	(0.006)
log(Whgt. Value Stated Balls)			-0.003	(0.010)
Truthful Statements			-0.068**	(0.033)
Wald $\mathcal{X}^2$	161.47***		232.20***	
Log-Likelihood	-360.51		-364.04	
Pseudo R^2	0.24		0.23	
N	842		842	
Number of clusters	211		211	

Round 2	Marginal Effects			
	Model (1)		**Model (2)**	
Player Characteristics				
Male	0.027	(0.045)	0.026	(0.044)
Age > 40	0.051	(0.045)	0.055	(0.044)
White	-0.123	(0.084)	-0.110	(0.082)
England	0.050	(0.049)	0.051	(0.049)
Order of Statements	-0.101**	(0.046)	-0.097**	(0.046)
Lied in Round 1	0.057	(0.038)	0.055	(0.038)
Cash-Criterion (CC)				
log(Value Open Balls)	-0.031***	(0.011)		
log(Value Stated Balls)	-0.002	(0.017)		
Truthful Statements	-0.146***	(0.049)		
Killer-Criterion (KC)				
No. Killers Open Balls	0.052	(0.049)		
No. Killers Stated Balls	0.071*	(0.040)		
Truthful Statements	-0.147***	(0.049)		
Cash-Killer-Criterion (CKC)				
log(Wght. Value Open Balls)			-0.034***	(0.008)
log(Wght. Value Stated Balls)			-0.020*	(0.012)
Truthful Statements			-0.191***	(0.041)
Wald $\mathcal{X}^2$	61.55***		69.99***	
Log-Likelihood	-368.25		-367.39	
Pseudo R^2	0.08		0.09	
N	631		631	
Number of Clusters	211		211	

standard errors in parentheses are corrected for episode clusters; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Note: 11 special episodes in which all players have the same sex are excluded.

Results

Looking at model (1) and (2) in Table 6, we find a significant race effect in round 1. Non-whites are voted off more frequently than whites. In round 2, the race effect disappears. But other personal player characteristics, as gender, age or place of residence, have no impact on the likelihood that a player is voted off the game in both rounds. Thus, the gender differences described in Section 6.2 seem to cancel out each other.
Addressing the order in which players make their statements each round, making a statement first has a significant impact on the likelihood to be voted to leave the game in round 2: If a player decides to state the content of her hidden back row balls first, the likelihood to stay in the game increases by roughly 10%. Thus our hypothesis of making the statement first allows players to credibly state “good” balls, is supported. As suggested, there is no significant effect of the order of statements in round 1.
Apart from that, we find no significant effect on the probability of being voted off in round 2 if a player lied in round 1, independent of the lie's content (overstatement or concealing a killer).
The variables representing the objective criteria have a strong explanatory power, with the highest Pseudo R^2 in model (2). As expected, concerning the open ball values on a players' front row, the higher the cash amount the lower a player's likelihood to be voted off. The reverse it true when addressing killer balls. The higher the number of killer balls in the open balls, the more likely a player is voted to leave the game. The statements about the hidden back row balls have no effect in round 1, and in round 2 only a statement about a killer ball is significant. This supports our suggestion that statements about cash values are meaningless, but that statements about killer balls are taken into account in the players' voting decision: Confessing a killer ball increases the likelihood of being voted off the game. Further, the variable indicating whether a player stated the truth, either about her hidden back row cash values or killer balls has a significant effect. In both rounds it is worthwhile to be honest, stating the truth reduces the likelihood to be voted off by roughly 10%. In round 2, the effect is even more pronounced, which might be due to the players' informational advantage about the ball values in play. Although the players have no information about the distribution of the hidden ball values in round 1, a player who states the truth seems to be able to signal credibility.[28]

For a more detailed analysis of the voting process, we draw our attention to the results from the ordered probit estimation, see Table 14 and Table 15 in Appendix A.3. There we can identify the effects on the number of votes a player receives.

[28]From a psychological perspective, people may recognize a liar with the help of certain body signals, for instance, avoiding eye contact, sweating, or blushing.

Overall, the results provided by the probit estimation above are confirmed.[29] In addition, we find that whether a player lied in round 1 matters for the probability of receiving zero or two votes in round 2. A player who lied before receives two votes 6% more likely than a player who made an honest statement.

Finally, we find that all effects are more pronounced in round 2 than in round 1. But, the explanatory power of both models decreases sharply between both rounds. In round 1, the cash- and killer-criterion in model (1) explain a 16% higher mass of the variance than in round 2 (Pseudo R^2=0.24 to Pseudo R^2=0.008), and the cash-killer-criterion in model (2) explains a 14% higher mass of the variance than model (2) in round 2 (R^2=0.23 to R^2=0.09). This decline serves as a further indicator for the switch between players' voting behavior. It is likely that players decide on whom to vote off the game by means of sympathy or trustworthiness. Unfortunately, we are not able to directly control for those effects.

Summary Our conjectures regarding player's strategy are largely confirmed in the data. As we expected, in round 1 neither player takes into account the statements about the hidden back row balls, and only decides on whom to vote by means of the *ex-ante* criteria. However, players discriminate against non-whites. On the contrary, in round 2 taste characteristics become meaningless, but players punish liars, i.e., liars have to bear the danger of being voted off more likely. Additionally, a player who decides to state the content of her hidden back row balls first is more likely to survive round 2. Surprisingly, the trustworthiness of players is highly valued in both rounds. Hence, strategic considerations, such as accumulating a high jackpot and selecting a cooperator as the final opponent, rather than player's characteristics appear to be the primary determinants of voting behavior in round 2.

7 Conclusion

In this paper we analyze cooperative behavior in a prisoner's dilemma game in the presence of high stakes, communication, and two rounds of pre-play, involving two voting decisions. Using data from 222 episodes of the British television game show "Golden Balls", we observe a unilateral cooperation rate of 55% and a mutual co-operation rate of 33%.
Summarizing our main results, we find that stake size, communication as well as pre-play have a significant impact on cooperation. Stake size is inversely related to

[29] The results on the probability of receiving two or three votes in round 1 or 2 are very similar to the ones from the probit model on the player's likelihood to be effectively voted off. This confirms the results, since receiving two or three votes (likely) results in the player's elimination from the game.

player's likelihood to cooperate, i.e., the higher the jackpot the more likely players are to defect. Further we can show that player's expectation about the stake size matters: If the jackpot is above (below) the player's expectation, the propensity to cooperate significantly decreases (increases), and mutual cooperation is less (more) successful. With respect to communication, certain words and gestures are more important than others. We test for the effect of handshakes and voluntarily stated mutual promises, and find that players who shake hands are more likely to defect, while handshakes in combination with a promise are likely to result in cooperation and successful coordination. The effects of stake size and communication are robust and independent of player characteristics and pre-play determinants.
The analysis of contestants' behavior in the pre-play shows that players make their voting decision dependent on objective criteria, i.e., their monetary contribution to the stake size, as well as on subjective personal characteristics of their opponents. We show that there is a strong link between the two rounds of pre-play and the players' decision in the prisoner's dilemma. Whether a player lied in the pre-play or contributed more to the stake size has a negative influence on cooperative behavior, whereas whether a player enjoys her opponent's goodwill has a positive one.

We are aware that there are potential drawbacks associated with the use of television game show data. The first addresses anonymity: Players on the show interact face-to-face and in front of large audience, including their family, friends, and colleagues. This might amplify cooperative behavior, e.g., a selfish-person might choose to cooperate only to avoid embarrassment or punishment by her peer group. The second addresses the selection of players for the show: Contestants are not randomly selected, but have to apply to the show. But, with respect to players exogenous personal characteristics, the sample can be considered, at least to some extent, as representative of the underlying (British) population.

This paper has shown that decisions in the prisoner's dilemma are influenced by the stake size, the player's expectation about stakes, and communication. We are not aware of any other study using handshakes and promises, as well as a player's expectation about stake size to explain cooperative behavior.

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Appendix

A.1 Instructions of the Prisoner's Dilemma

The show host Jasper Carrott explains the "weak" prisoner's dilemma in every episode with almost the same words:

> "It is time to split or steal. You have got two final golden balls left, you have each got a golden ball with the word *split* written inside, you have got each a golden ball with the word *steal* written inside. I will ask you to make a conscious choice and you will choose either the split or the steal ball, neither of you will know what the other has chosen. If you both choose the split balls, you split today's jackpot of £J and you both go home with £$J/2$. If one of you splits and one of you steals, whoever steals goes home with all the money £J, whoever splits goes home with nothing. If you both decide to steal and you are very greedy, you both go home with nothing. Before I ask you to choose, Player A, B just check the two balls to make sure you know which is to split and which is to steal. Do not show to each other. It is very important that you know which is which. [PLAYERS CHECK THE BALLS] Are you happy to know which is split and which is steal? Okay, before I ask you to choose, I will give you some time to talk to each other about what has happened today and how you feel. [PLAYERS DISCUSS] Okay, player A, B choose the split or steal ball now. [PLAYERS CHOOSE BALLS] Hold it up, make sure that when you open it, the other player can see it. Player A, B split or steal? [PLAYERS OPEN BALLS]"

A.2 An Alternative Empirical Strategy

In Section 5, we have shown which factors significantly influence cooperative behavior. In this section we present an alternative approach. Before the show starts, contestants are individually asked to make a private statement about the strategy they plan to play in case they reach the final round (see Section 3.2). These filmed statements are broadcasted to the television audience, but cannot be observed by the contestants.

We observe an unambiguous strategy-statement by 59% of the final players. Given these individual statements, we can infer whether contestants stick to their announced strategy, i.e., behave consistently or not. If players are either defectors or cooperators, independent of the situation and their opponent, we should neither observe switching strategies nor significant effects of any explanatory variables.

In Table 7 we depict the average cooperation rate depending on the players' strategy-statement.

Interestingly, the raw data show that contestants more often state to steal than to split (33,3% versus 25,7%). But we find that players switch their strategy significantly more often (p=0.008) if they initially planned to steal (35.3% split) than if they planned to split (22.9% steal). Addressing the players who do not explicitly state their strategy, we

Table 7: Relation between commitment and the cooperation rate

			Decision	
Statement	N	%	Steal (%)	Split (%)
Steal	136	33,3	64.7	35.3
Split	105	25,7	22.9	77.1
Ambiguous	167	43,1	43.1	56.9
Total	408[a]	100	45.1	54.9

[a] Note, that the strategy-statement is not filmed in the first 18 episodes. This reduces the data set to 204 episodes (408 players).

find that 56.9% actually split. The difference between those and the observed average cooperation rate (54,5%) is not significant (p=0.587).

Thus, one could surmise that a substantial fraction of players are of a certain type, either cooperators or defectors. The ones that change their strategy make their strategy dependent on the events in the game as well as on opponent characteristics. We therefore can conclude that at least 17.6% of the players have situation dependent social preferences.

A.3 Tables

Table 8: Cooperation rates by gender, series, demographics, and stake size

	Split			
	Men (N=207)	Women (N=237)	All (N=444)	
	Row %	Row %	Row %	**N**
Experience				
Unexperienced (Series 1)	44.4	59.1	52.5	80
Experienced (Series 2-4)	55.0	54.9	54.9	364
Age				
≤ 40	44.3	53.1	49.2	260
> 40	64.1	59.8	62.0	184
Race				
Non-White	46.2	42.9	44.4	27
White	53.6	56.5	55.2	417
England				
Not from England	73.3	70.7	71.8	71
From England	49.4	52.3	50.9	371
Jackpot in £				
$[3, 500]$	71.4	75.7	73.6	72
$(500, 2500]$	50.9	55.6	53.0	100
$(2500, 10000]$	56.0	50.0	52.9	102
$(10000, 30000]$	43.2	51.4	48.3	116
$(30000, 100150]$	43.5	51.6	48.1	54
Potential Jackpot in £				
$[5000, 30000]$	46.3	51.7	49.1	114
$(30000, 45000]$	49.3	58.5	53.6	138
$(45000, 75000]$	52.3	58.3	55.8	104
$(75000, 168100]$	72.2	53.8	61.4	88
Expectation				
Jackpot $<$ Expectation	58.3	59.5	58.9	292
Jackpot $\geq$ Expectation	41.3	49.4	46.1	152
Total	53.1	55.7	54.5	444

Table 9: Mutual decision outcomes by series, demographics and stake size

	(steal, steal)	**(steal, split)**	**(split, split)**	
	Row %	Row %	Row %	**N**
Experience				
Unexperienced (Series 1)	25.0	45.0	30.0	80
Experienced (Series 2-4)	24.2	41.8	34.1	364
Gender				
Male Team	35.3	32.4	32.4	68
Female Team	16.3	55.1	28.6	98
Mixed Team	24.5	40.3	35.3	278
Age				
Old Team (> 40)	11.8	50.0	38.2	68
Young Team (≤ 40)	23.6	48.6	27.8	144
Mixed Team	28.4	36.2	35.3	232
England				
Not English Team	25.0	25.0	50.0	8
English Team	28.6	39.0	32.5	308
Mixed Team	14.3	52.4	33.3	126
Jackpot				
$\leq$ £500	8.3	36.1	55.6	72
$>$ £500	27.4	43.5	29.0	372
Expectation				
Jackpot $<$ Expectation	23.3	35.6	41.1	292
Jackpot $\geq$ Expectation	26.3	55.3	18.4	152
Total	24.3	42.3	33.3	444
Average Winnings	(0, 0)	(15693, 0)	(4784, 4784)	444

Table 10: Results from ordered probit on outcomes in the PD (2)

$y = 0; 1; 2$	Marginal Effects[a]					
	Steal/Steal (0)		**Split/Steal (1)**		**Split/Split (2)**	
Player Characteristics						
Team Unexperienced	0.015	(0.066)	0.003	(0.010)	-0.018	(0.075)
Team Male	0.094	(0.088)	0.005	(0.011)	-0.099	(0.082)
Team Female	0.020	(0.064)	0.003	(0.010)	-0.023	(0.074)
Team > 40	-0.065	(0.067)	-0.021	(0.030)	0.086	(0.097)
Team < 40	0.104	(0.065)	0.012	(0.011)	-0.116	(0.069)
Team England	0.109**	(0.051)	0.034	(0.023)	-0.143**	(0.070)
Team Small City	0.069	(0.049)	0.013	(0.012)	-0.082	(0.058)
Index	-0.332**	(0.165)	-0.065	(0.047)	0.397**	(0.197)
Pre-Play						
Team Never Lied	-0.055	(0.059)	-0.016	(0.023)	0.070	(0.081)
Team Lying	0.029	(0.052)	0.005	(0.009)	-0.035	(0.061)
Communication						
Handshakes	0.097	(0.097)	0.019	(0.015)	-0.116	(0.110)
Promise	-0.062	(0.101)	0.125***	(0.021)	0.075	(0.119)
Handshakes*Promise	-0.327***	(0.109)	0.035	(0.085)	0.361***	(0.134)
Stake Size						
Jackpot < Expectation	-0.161***	(0.055)	-0.013	(0.015)	0.174***	(0.056)
Wald $\mathcal{X}^2$	28.98**					
Log-Likelihood	-223.65					
Pseudo R^2	0.06					
N	54		94		74	
Number of clusters	222					

Standard errors in parentheses are corrected for episode clusters; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 11: Voting decision by means of objective criteria

	After round 1[b]		**After round 2**	
Criteria to predict a player	**in**	**out**	**in**	**out**
who should be voted to leave[a]	Row %	Row %	Row %	Row %
Cash-Criterion (CC)				
ex-ante				
stay	87.2	12.8	72.3	27.7
vote to leave	38.3	61.7	55.4	44.6
stated				
stay	76.7	23.3	70.0	30.0
vote to leave	69.8	30.2	59.9	40.1
ex-post				
stay	83.0	17.0	74.8	25.2
vote to leave	50.9	49.1	50.5	49.5
Killer-Criterion (KC)				
ex-ante				
stay	92.0	8.0	83.6	16.4
vote to leave	23.9	76.1	32.9	67.1
stated				
stay	93.7	6.3	85.1	14.9
vote to leave	18.9	81.1	29.7	70.3
ex-post				
stay	86.6	13.4	80.9	19.1
vote to leave	40.1	59.9	38.3	61.7
Cash-Killer-Criterion (CKC)				
ex-ante				
stay	87.7	12.3	73.2	26.8
vote to leave	36.9	63.1	53.6	46.4
stated				
stay	83.3	16.7	74.1	25.9
vote to leave	50.0	50.0	51.8	48.2
ex-post				
stay	83.2	16.8	74.5	25.5
vote to leave	50.5	49.5	50.9	49.1
N	666	222	444	222

[a] We take into account that the prediction might not be unique per episode, i.e., more than one player might have a prediction to be eliminated.

[b] Each round, 222 contestants are eliminated. In round 1 (2) 55.4% (52.2%) of the eliminated players are men.

Table 12: Voting decision per player by means of objective criteria

Players voted by means of	**all (%)**	**men (%)**	**women (%)**
Cash-Criterion (CC)			
ex-ante			
Round 1	72.4	74.5	70.5
Round 2	66.5	67.3	65.8
stated			
Round 1	36.0	38.5	33.6
Round 2	64.4	62.6	66.1
ex-post			
Round 1	55.3	55.4	55.3
Round 2	70.2	66.9	73.2
Killer-Criterion (KC)			
ex-ante			
Round 1	82.1	83.0	81.3
Round 2	81.9	84.9	79.1
stated			
Round 1	83.6	85.5	81.8
Round 2	78.9	80.2	77.6
ex-post			
Round 1	70.9	72.7	69.2
Round 2	76.3	77.0	75.6
Cash-Killer-Criterion (CKC)			
ex-ante			
Round 1	71.0	74.1	68.1
Round 2	65.8	67.3	64.4
stated			
Round 1	55.0	58.3	51.9
Round 2	63.5	61.9	65.1
ex-post			
Round 1	60.4	61.5	59.3
Round 2	66.8	65.5	68.1
N[a]	573	278 (48.5%)	295 (51.5%)

[a] Note: For purpose of comparability, we restrain the sample to 573 observations including only those players, who are not being eliminated in round 1. Further we consider only those decisions for which we can trace back for whom a player voted, i.e., we exclude episodes with a voting of 2:1:1:0 in round 1 and 1:1:1 in round 2.

Table 13: Voting decision per player under risk or ambiguity (by means of objective criteria)

Players vote by means of	Round 2 Uncertainty (%)	Round 2 Partial Ambiguity (%)	Round 2 Ambiguity (%)	Round 1 Ambiguity (%)
Cash-Criterion (CC)				
ex-ante				
all	64.0	66.3	67.2	72.4
men	82.4	64.9	67.7	74.5
women	54.5	67.6	66.7	70.5
stated				
all	58.0	67.7	61.8	36.0
men	52.9	65.7	60.6	38.5
women	60.6	69.6	63.2	33.6
ex-post				
all	74.0	70.2	69.3	55.3
men	70.6	66.4	66.9	55.4
women	75.8	73.6	71.9	55.3
Killer-Criterion (KC)				
ex-ante				
all	84.3	79.8	84.0	82.1
men	82.4	81.3	89.1	83.0
women	85.3	78.4	78.3	81.3
stated				
all	84.0	75.9	81.3	83.6
men	94.1	76.9	81.9	85.5
women	78.8	75.0	80.7	81.8
ex-post				
all	78.0	75.2	77.2	70.9
men	88.2	76.9	75.6	72.7
women	72.7	73.6	78.9	69.2
Cash-Killer-Criterion (CKC)				
ex-ante				
all	60.0	64.9	68.0	71.0
men	76.5	62.7	70.9	74.1
women	51.5	66.9	64.9	68.1
stated				
all	70.0	61.7	64.3	55.0
men	70.6	59.0	63.8	58.3
women	69.7	64.2	64.9	51.9
ex-post				
all	76.0	66.3	65.6	60.4
men	88.2	64.9	63.0	61.5
women	69.7	67.6	68.4	59.3
N[a]	50	282	241	573

[a] Note: The sample is restricted to the same 573 players in round 1 and 2.

Table 14: Ordered probit regression results on the number of votes (round 1)

$y_{ie} = 0; 1; 2; 3$ (Number of votes a player receives in round 1 per episode)

		Marginal Effects			
No. of Votes	**Variables**	Model (1)		Model (2)	
0	**Player Characteristics**				
	Male	-0.051	(0.035)	-0.051	(0.035)
	Age > 40	0.012	(0.034)	0.015	(0.034)
	White	0.135**	(0.058)	0.126**	(0.059)
	England	-0.009	(0.045)	-0.002	(0.046)
	Order of Statements	0.021	(0.042)	0.016	(0.042)
	Cash-Criterion (CC)				
	log(Value Open Balls)	0.097***	(0.010)		
	log(Value Stated Balls)	-0.025	(0.019)		
	Truthful Statements	0.111***	(0.036)		
	Killer-Criterion (KC)				
	No. Killers Open Balls	-0.159***	(0.040)		
	No. Killers Stated Balls	-0.007	(0.050)		
	Truthful Statements	0.148***	(0.037)		
	Cash-Killer-Criterion (CKC)				
	log(Wght. Value Open Balls)			0.110***	(0.007)
	log(Wght. Value Stated Balls)			-0.011	(0.012)
	Truthful Statements			0.138***	(0.036)
1	**Player Characteristics**				
	Male	0.007	(0.005)	0.008	(0.006)
	Age > 40	-0.002	(0.005)	-0.002	(0.005)
	White	-0.005	(0.005)	-0.008**	(0.004)
	England	0.001	(0.006)	0.000	(0.007)
	Order of Statements	-0.003	(0.006)	-0.003	(0.007)
	Cash-Criterion (CC)				
	log(Value Open Balls)	-0.013***	(0.002)		
	log(Value Stated Balls)	0.003	(0.003)		
	Truthful Statements	-0.011***	(0.004)		
	Killer-Criterion (KC)				
	No. Killers Open Balls	0.021***	(0.007)		
	No. Killers Stated Balls	0.001	(0.007)		
	Truthful Statements	-0.012***	(0.003)		
	Cash-Killer-Criterion (CKC)				
	log(Wght. Value Open Balls)			-0.017***	(0.003)
	log(Wght. Value Stated Balls)			0.002	(0.002)
	Truthful Statements			-0.022***	(0.007)
2	**Player Characteristics**				
	Male	0.025	(0.017)	0.024	(0.017)
	Age > 40	-0.006	(0.016)	-0.007	(0.016)
	White	-0.064**	(0.027)	-0.060**	(0.028)
	England	0.004	(0.022)	0.001	(0.022)
	Order of Statements	-0.010	(0.020)	-0.008	(0.020)
	Cash-Criterion (CC)				
	log(Value Open Balls)	-0.047***	(0.006)		
	log(Value Stated Balls)	0.012	(0.009)		
	Truthful Statements	-0.053***	(0.018)		
	Killer-Criterion (KC)				
	No. Killers Open Balls	0.076***	(0.020)		
	No. Killers Stated Balls	0.003	(0.024)		
	Truthful Statements	-0.071***	(0.019)		
	Cash-Killer-Criterion (CKC)				
	log(Wght. Value Open Balls)			-0.052***	(0.005)
	log(Wght. Value Stated Balls)			0.005	(0.006)
	Truthful Statements			-0.066***	(0.018)
3	**Player Characteristics**				
	Male	0.020	(0.014)	0.019	(0.013)
	Age > 40	-0.005	(0.013)	-0.005	(0.013)
	White	-0.066*	(0.036)	-0.058*	(0.034)
	England	0.003	(0.017)	0.001	(0.017)
	Order of Statements	-0.008	(0.016)	-0.006	(0.015)
	Cash-Criterion (CC)				
	log(Value Open Balls)	-0.037***	(0.005)		
	log(Value Stated Balls)	0.010	(0.007)		
	Truthful Statements	-0.046***	(0.016)		
	Killer-Criterion (KC)				
	No. Killers Open Balls	0.061***	(0.016)		
	No. Killers Stated Balls	0.003	(0.019)		
	Truthful Statements	-0.066***	(0.019)		
	Cash-Killer-Criterion (CKC)				
	log(Wght. Value Open Balls)			-0.041***	(0.004)
	log(Wght. Value Stated Balls)			0.004	(0.004)
	Truthful Statements			-0.051***	(0.013)
	Wald $\mathcal{X}^2$	284.59***		390.05***	
	Log-Likelihood	-875.00		-870.64	
	Pseudo R^2	0.18		0.19	
	N	842		842	
	Number of clusters	211		211	

standard errors in parentheses are corrected for episode clusters; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Note: 11 special episodes are excluded (all players have the same sex)

Table 15: Ordered probit regression results on the number of votes (round 2)

$y_{ie} = 0; 1; 2$ (Number of votes a player receives in round 1 per episode)

		Marginal Effects			
No. of Votes	**Variables**	Model (1)		Model (2)	
0	**Player Characteristics**				
	Male	-0.002	(0.037)	-0.002	(0.037)
	Age > 40	-0.030	(0.035)	-0.033	(0.035)
	White	0.039	(0.074)	0.031	(0.076)
	England	-0.045	(0.041)	-0.047	(0.042)
	Order of Statements	0.175***	(0.046)	0.170***	(0.045)
	Lied in Round 1	-0.065**	(0.031)	-0.062**	(0.031)
	Cash-Criterion (CC)				
	log(Value Open Balls)	0.036***	(0.009)		
	log(Value Stated Balls)	0.005	(0.015)		
	Truthful Statements	0.177***	(0.047)		
	Killer-Criterion (KC)				
	No. Killers Open Balls	-0.047	(0.040)		
	No. Killers Stated Balls	-0.044	(0.033)		
	Truthful Statements	0.014	(0.054)		
	Cash-Killer-Criterion (CKC)				
	log(Wght. Value Open Balls)			0.040***	(0.007)
	log(Wght. Value Stated Balls)			0.017*	(0.010)
	Truthful Statements			0.182***	(0.034)
1	**Player Characteristics**				
	Male	0.000	(0.000)	0.000	(0.000)
	Age > 40	-0.000	(0.001)	-0.000	(0.001)
	White	0.002	(0.008)	0.001	(0.006)
	England	0.002	(0.004)	0.002	(0.004)
	Order of Statements	-0.014*	(0.007)	-0.013*	(0.007)
	Lied in Round 1	-0.000	(0.001)	-0.000	(0.001)
	Cash-Criterion (CC)				
	log(Value Open Balls)	-0.000	(0.001)		
	log(Value Stated Balls)	-0.000	(0.000)		
	Truthful Statements	0.004	(0.003)		
	Killer-Criterion (KC)				
	No. Killers Open Balls	0.000	(0.001)		
	No. Killers Stated Balls	0.000	(0.001)		
	Truthful Statements	0.000	(0.001)		
	Cash-Killer-Criterion (CKC)				
	log(Wght. Value Open Balls)			-0.000	(0.001)
	log(Wght. Value Stated Balls)			-0.000	(0.000)
	Truthful Statements			0.004	(0.003)
2	**Player Characteristics**				
	Male	0.002	(0.037)	0.002	(0.037)
	Age > 40	0.030	(0.036)	0.034	(0.036)
	White	-0.041	(0.082)	-0.032	(0.082)
	England	0.043	(0.037)	0.044	(0.038)
	Order of Statements	-0.161***	(0.039)	-0.157***	(0.039)
	Lied in Round 1	0.066**	(0.031)	0.062**	(0.031)
	Cash-Criterion (CC)				
	log(Value Open Balls)	-0.036***	(0.010)		
	log(Value Stated Balls)	-0.005	(0.015)		
	Truthful Statements	-0.181***	(0.049)		
	Killer-Criterion (KC)				
	No. Killers Open Balls	0.047	(0.040)		
	No. Killers Stated Balls	0.044	(0.033)		
	Truthful Statements	-0.014	(0.055)		
	Cash-Killer-Criterion (CKC)				
	log(Wght. Value Open Balls)			-0.040***	(0.007)
	log(Wght. Value Stated Balls)			-0.017*	(0.010)
	Truthful Statements			-0.186***	(0.036)
	Wald $\mathcal{X}^2$	102.47***		110.81***	
	Log-Likelihood	-634.79		-633.74	
	Pseudo R^2	0.08		0.09	
	N	631		631	
	Number of clusters	211		211	

standard errors in parentheses are corrected for episode clusters; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Note: 11 special episodes are excluded (all players have the same sex)

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